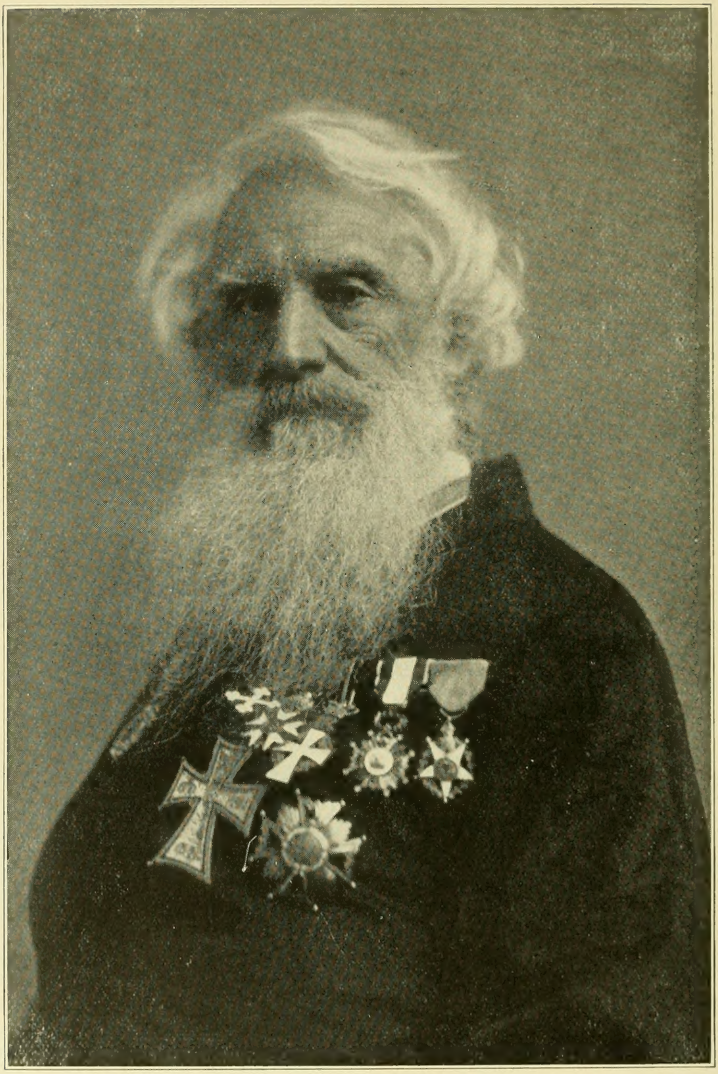

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Grateful acknowledgment is here made also for the invaluable co-operation of the foremost engineering firms and manufacturers in making these volumes thoroughly representative of the very best and latest practice in the design, construction, and operation of electrical machinery and instruments; also for the valuable drawings, data, suggestions, criticisms, and other courtesies.

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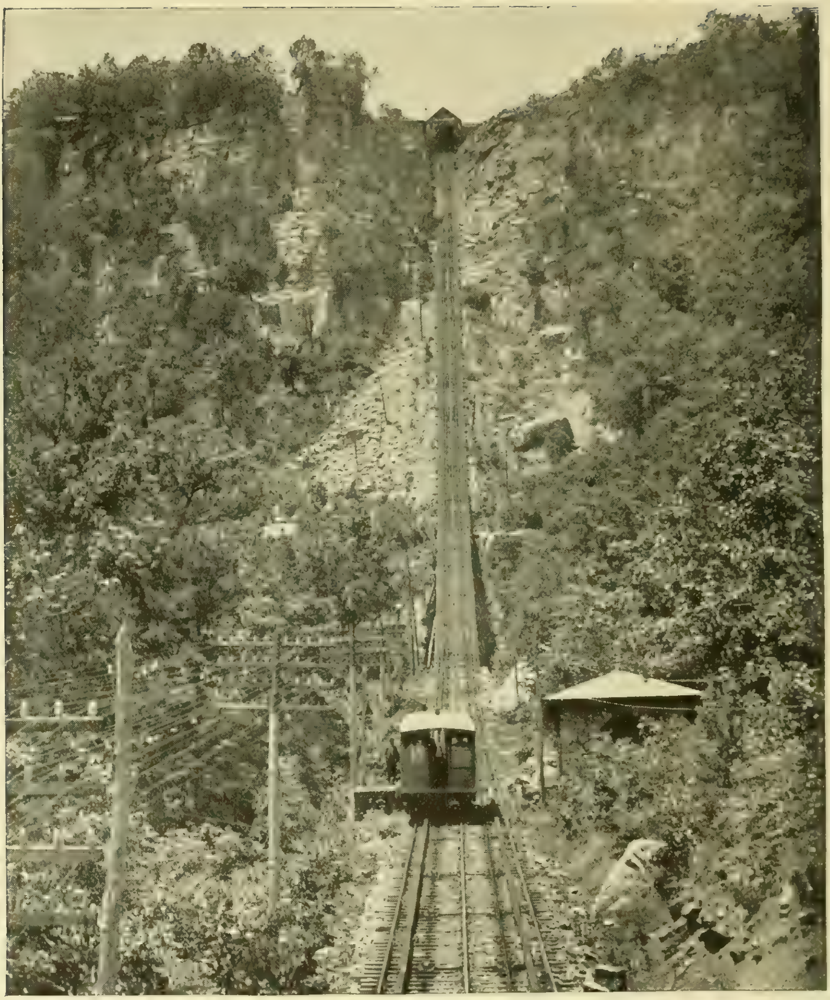

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Foreword

ONE of the simplest acts in modern life is switching on the electric current that gives light or power, or that makes possible communication between distant points. A child can perform that act as effectively as a man, so thoroughly has electricity been broken to the harness of the world's work; but behind that simple act stand a hundred years of struggle and achievement, and the untiring labors of thousands of the century's greatest scientists. To compact the results of these labors into the compass of a practical reference work is the achievement that has been attempted — and it is believed accomplished—in this latest edition of the Cyclopedia of Applied Electricity.

¶ Books on electrical topics are almost as many as the subjects of which they treat, and all of them, if gathered into a great common library, would contain so many duplicate pages that their use would entail an appalling waste of time upon the man who is trying to keep up with electrical progress. To overcome this difficulty the publishers of this Cyclopedia went direct to the original sources, and secured as writers of the various sections, men of wide practical experience and thorough technical training, each an acknowledged authority in his work; and these contributions have been correlated by our Board of Editors into a logical and unified whole.

¶ The Cyclopedia is, therefore, a complete and practical working treatise on the generation and application of electric power.

It covers the known principles and laws of Electricity, its generation by dynamos operated by steam, gas, and water power; its transmission and storage; and its commercial application for purposes of power, light, transportation, and communication. It includes the construction as well as the operation of all plants and instruments involved in its use; and it is exhaustive in its treatment of operating "troubles" and their remedies.

¶ The Cyclopedia is as thoroughly scientific as any work could be; but its treatment is as free as possible from abstruse mathematics and unnecessary technical phrasing, while it gives particular attention to the careful explanation of involved but necessary formulas. Diagrams, curves, and practical examples are used wherever they may be helpful in explaining the subject under discussion.

¶ The Cyclopedia is a compilation of many of the most valuable Instruction Books of the American School of Correspondence, and the method adopted in its preparation has been found to be the best devised for the education of the busy, practical man.

¶ A glossary of the electrical terms used in this Cyclopedia will be found in Volume VII. The definitions are given in simple language and, where it was thought desirable, reference has been made to the volume and page where the reader may find added matter on the topic sought.

¶ Attention is directed to a bibliography of the best literature in Electrical Engineering, in Volume VII. No attempt has been made to exhaust the sources but merely to provide the names, authors, and publishers of books which would appeal to the widest circle of readers.

¶ In conclusion, grateful acknowledgment is due to the staff of authors and collaborators, without whose hearty co-operation this work would have been impossible.

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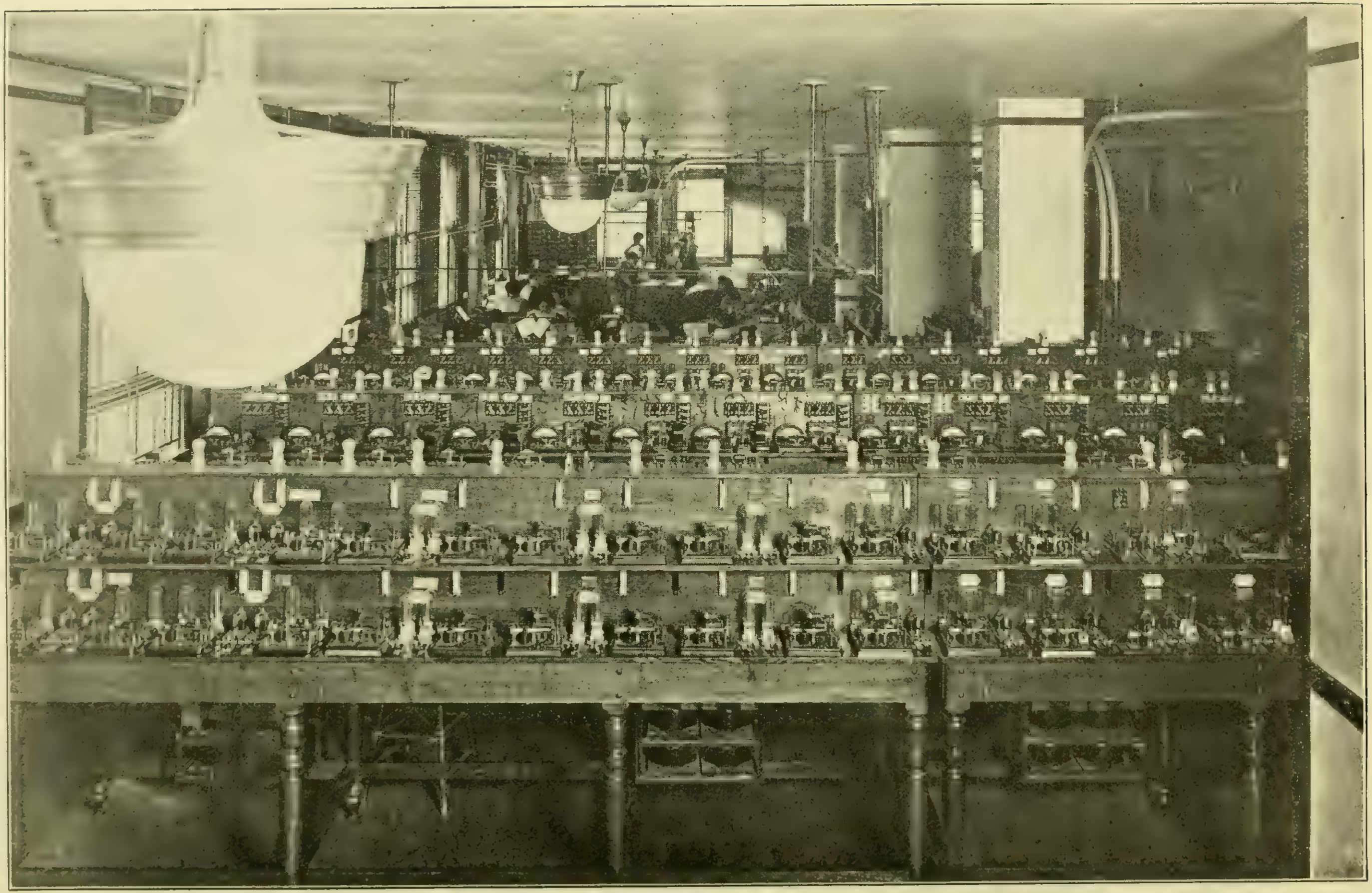

MULTIPLEX DEPARTMENT OF WESTERN UNION OFFICE, OMAHA, NEBRASKA

Courtesy of Western Union Telegraph Company

MODERN LAND AND SUBMARINE TELEGRAPHY

HISTORICAL INTRODUCTION

The word "telegraph" is derived from two Greek words meaning "to write" "afar", but the meaning of the term has never been limited to devices that "write". At present, the word "telegraph" means a device or a system of devices with which, by means of signals, it is possible to transmit intelligence from one point to another.

Visible Signal Transmission. It is not possible to determine the exact date when or the manner in which signal transmission was first employed, but it is not improbable that prehistoric man was able to communicate to distant friends warnings of danger by means of signals made by lights or sounds. In fact, tribes are still found in Africa who transmit over considerable distance a variety of information by means of rude instruments like drums. One of the earliest definite records of telegraph invention is that referring to a system invented by Locke in 1684 employing large wood blocks which could be arranged in various groups and displayed so as to be seen and interpreted by an observer at a distant station. This invention, like many others, was never put into practical use, due possibly as much to the lack of demand for such transmission of information as to the defects in the system itself. Such a demand arose about one hundred years later in an interesting manner, and it was met by the ingenuity of two brothers, Claude and Ignace Chappé, who were living in separate college buildings in Angers, France. Under the rules of the college, these brothers were not permitted to communicate with each other and in order to do so they devised a system of semaphore signals which could be so displayed as to be visible from one building to the other. The semaphore consisted of two arms—a long arm arranged to swing about a fixed point and a short arm hinged to the free end of the long arm, so that they could be set at various angles. With this device the Chappé brothers were able to make nearly two hundred distinct signals which by a prearranged code enabled them to carry on conversation. This was the beginning of a very extensive system later developed for the French Government under the direction of Claude Chappé, who was appointed Chief Telegraph Engineer. A series of signal towers were erected at suitable distances along the route so that the signals displayed in the first tower could be seen from the second tower and there displayed within sight of an observer in a third tower. Similarly the signals could be displayed by successive towers to the end of the system. Modifications of, and improvements in, this system were made by several others, one of these, the Murray system, being adopted by the British Government about 1800. In 1834, an improved system was devised which was capable of transmitting over four thousand distinct signals. During the first half of the nineteenth century, semaphore telegraphs were extended over a large part of Europe. In 1825, such a system was in operation between Sandy Hook and New York City, and for a number of years it was a successful competitor of an electromagnetic telegraph between the same points. Certain adaptations of this system are still in extensive practical operation, as for instance the railroad semaphore signals and the "ship's telegraph" used aboard ship.

DEVELOPMENT OF ELECTRIC TELEGRAPH

Progress in Electrical Theory. It so happened that about the same time that Locke proposed his block telegraph system (1684), interest in electrical science was just beginning to awaken, due largely to the invention of electric machines by Von Guericke (1672) and Newton (1675). When, about one hundred years later, Chappé produced his semaphore telegraph, Gray had discovered and classified conductors and insulators; Watson had discharged Leyden jars through about four miles of wire; and Galvani had discovered current electricity. It was, therefore, natural that many persons should seriously consider the use of electricity for the operation of telegraphs. During the decade from 1820 to 1830, wonderful developments were made in electrical science, especially in electromagnetism, and its application to practical devices was a popular subject for study. Oersted had discovered the relation between the electric current and magnetism; and Faraday had experimentally produced electricity from magnetism. Henry had made important discoveries in connection with the production of magnetism from electricity, having produced electromagnets capable of being operated through wires of considerable length. Gauss published a theory of magnetism and Webber developed methods of electric-current measurement. As a result of this activity, at least three groups of inventors began exhaustive study along lines which led to practical results. There were Gauss, Webber, and Steinheil in Germany; Cooke and Wheatstone in England; Henry and Morse in America.

Steinheil Telegraph. Steinheil was engaged by Gauss to develop apparatus which had been invented by Gauss and Webber. The transmitter being of the magneto type required no battery but produced impulses of current, alternating in polarity, by the movement back and forth of a strong permanent magnet. The original Gauss-Webber receiver was practically Webber's mirror galvanometer, which would deflect a beam of light to the right or left according to the polarity of the impulse generated by the transmitter. A given number of swings in each direction represented the various letters of the alphabet. Steinheil made several improved forms of receivers, including an ink writing recorder. This telegraph required only one circuit and it appears to have operated satisfactorily over short lines but was not successfully operated over long lines.

Cooke-Wheatstone Telegraph. The first Cooke-Wheatstone telegraph actually operated employed six line wires, the general plan being shown in Fig. 1. The receiver contained five coils, connected to five respective line circuits. In the center of each coil was a magnetic needle which, when current was sent through the coil, would deflect to the right or left, depending on the direction of the current through the coil and line. The transmitter consisted of a group of strap key switches so arranged and connected that, by pressing the corresponding straps, any of the six line wires would be brought in contact with either terminal of the battery.

The letters and figures were arranged in rows on a diamond-shaped plate, as shown in Fig. 1. To send a letter, two keys on the transmitter would be pressed, one connecting one line circuit to the positive (+) battery terminal and the other connecting a line circuit to the negative (−) battery terminal. For example if the letter R is to be signaled, one would press a + key on line 5 and a − key on line *3*; this would cause the needle in coil *5* to swing to the left and the needle in coil *3* to swing to the right, as shown in the figure. The needle *5* indicates that the desired letter is in row MY and the needle *3* indicates it is in row GR, the letter is therefore the one at

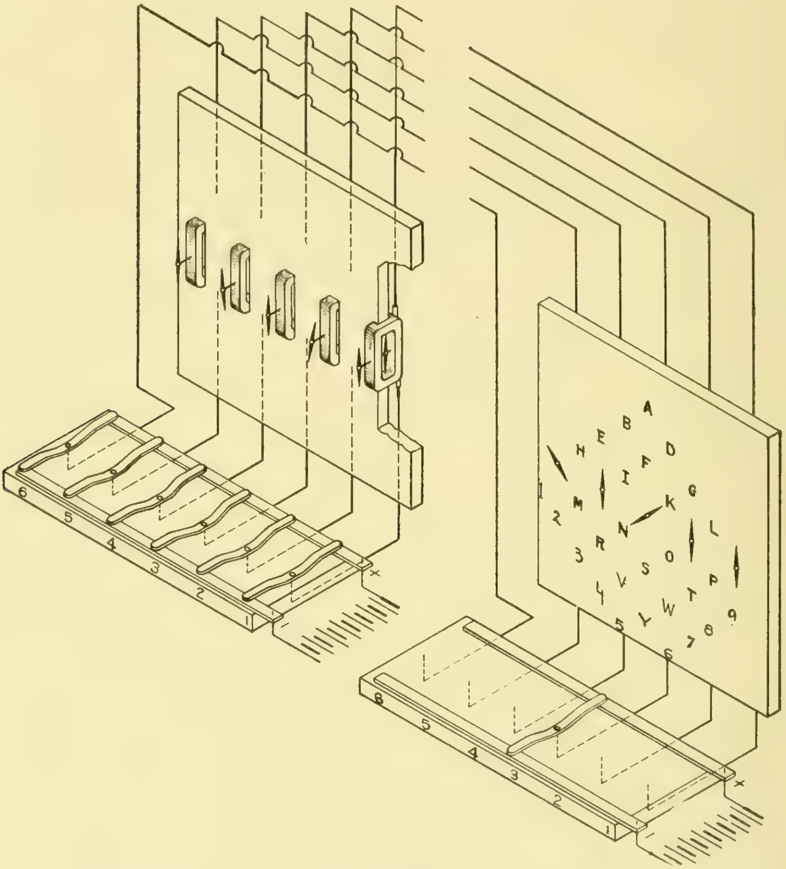

Fig. 1. Diagram of General Plan of Cooke-Wheatstone Telegraph, Operated Over a Thirteen Mile Line in 1838

the intersection of these rows, which is R. Similarly if keys *2*+ and *4*− were pressed, the needles would indicate letter F, or if *6*+ and *4*−, the figure 2 would be indicated. This system was operated over a line about 13 miles long during 1838. Some years later (1845) a new Cooke-Wheatstone system was developed in which there were but one line wire and a single needle which could be deflected either to the right or left as before, but with this a code was used and a given number of swings to the right or left indicated a given letter or figure. Such needle telegraphs have been very largely used in England and are even today employed there on some railways and in the less important offices.

Morse Telegraph. Although not directly associated with Morse in the invention of the telegraph, Professor Joseph Henry, as early as 1829, began investigations which essentially assisted in the production of the Morse telegraph. It was Henry who first showed how to make electromagnets that would operate over long wires, and it has been claimed by many that Henry actually had electromagnetic telegraphs in operation in Albany, New York, several years before Morse began his experimental work. Be that as it may, it is certain that Morse, about 1835, made use of the type of electromagnet produced by Professor Henry at least five years before. The Morse instruments were not given much publicity before 1837, at which time Alfred Vail became associated with Morse. The first working model of the Morse telegraph was made about 1835, Fig. 2. The transmitting device consisted of a double contact mercury circuit-breaker operated so as to make and break the circuit at intervals corresponding to projections on wood type blocks shown at the top of the figure. Each type block represented one figure, from 0 to 9, depending upon the number and positions of the projections. Combinations of figures could be set up to represent any number, and each number represented a word in a dictionary specially prepared by Morse. The recorder consisted of a small electromagnet which, when excited by a current, would attract its armature and cause a pencil to move transversely across a paper tape, while the tape was being moved longitudinally with uniform velocity by clockwork. The result was a straight line broken by the transverse movement whenever the line circuit, which included the electromagnet winding, was opened or closed.

After a partnership was arranged between Morse and Vail, many changes were made in the form of the apparatus. The so-called "Morse Code" was developed to signal letters as well as figures. The recorder was made much smaller and it was soon given practically the proportions which are standard today; in place of the cumbersome transmitting device with its type blocks, a simple hand-operated key switch was substituted, and the code of signals was much simplified. The telegraph thus improved was publicly exhibited and operated with a view to obtaining financial assistance for the construction of practical telegraph lines, but it was not until 1843 that such aid was obtained. In the face of much opposition and even ridicule, Congress finally passed a bill appropriating $30,000 for the construction of an experimental telegraph line be-

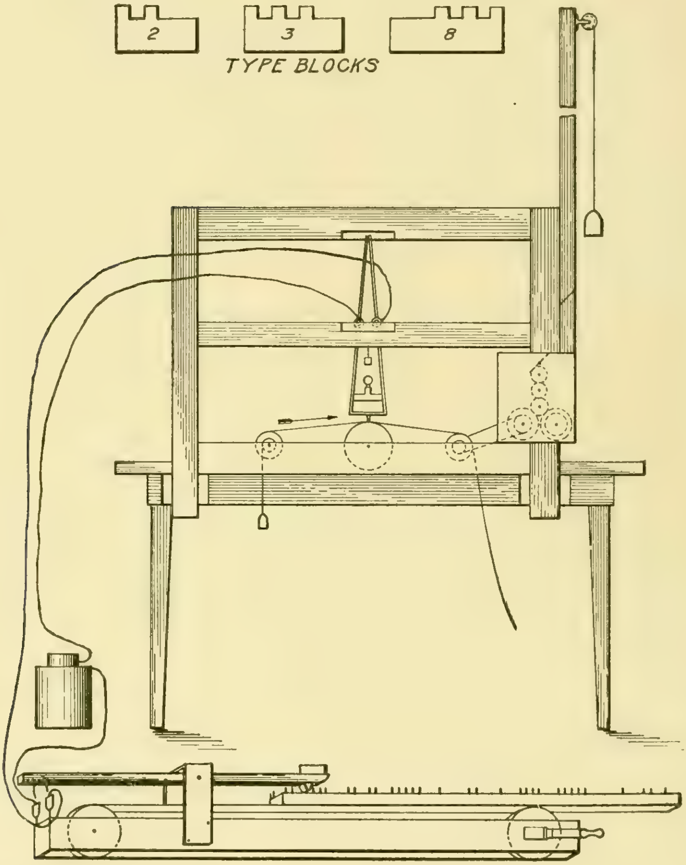

*Fig. 2. Morse Telegraph, 1838 Model

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* From Prescott's "Electric Telegraph."

tween Washington and Baltimore. This line was planned by Morse as an underground line but, as such, portions of it failed utterly. The line was finally completed as an overhead pole line in May, 1844; its successful completion being due mainly to the persistence of Ezra Cornell, the Superintendent of Construction. The system was formally opened on May 29, 1844, by the transmission of the memorable message "What hath God wrought."

A view of the recorder which received this message at Baltimore is shown in Fig. 3. This recorder, built by Alfred Vail, was originally equipped with a fountain pen, but later was fitted with an embossing stylus as shown. It is instructive to note that although Morse had thus publicly demonstrated the possibility, and even the practicability, of electric telegraphy, yet the general public did not feel any real necessity for such rapid transmission of intelligence.

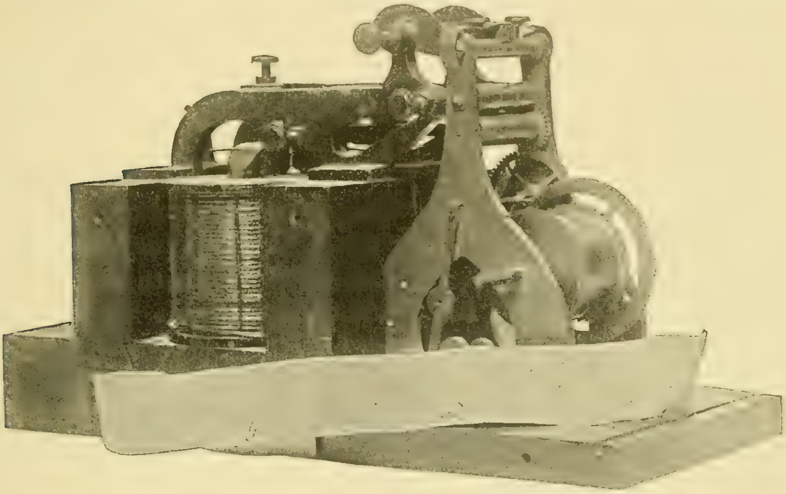


Fig. 3. Morse Recorder Used to Receive the Memorable Message, "What Hath God Wrought", at Baltimore, May 27, 1844

In fact Morse and his associates offered the telegraph to the United States Government for the sum of $100,000. The proposal was referred to the Postmaster General who reported that "although the invention is an agent vastly superior to any other ever devised by the genius of man . . . yet the operation between Washington and Baltimore has not satisfied me that under any rate of postage that can be adopted, its revenues can be made to cover its expenditure."

In comparing the merits of the three telegraph systems which were originally announced in 1837—namely, the Steinheil, the Cooke-Wheatstone, and the Morse—it is to be noted that the Morse telegraph was more simple, more complete, more rapid, and capable of operation over longer lines than the others. It is probably true that much of the success of the Morse system was due to the work of other men, but Morse was the one who, directly or indirectly, brought together those men to do for him the work which resulted in successfully placing the electric telegraph at the service of the public; and this fact coupled with the simplicity, completeness, and capability of his system, probably even more than his claims of priority in invention, has caused Professor Morse to be generally acclaimed the "Father of the Electric Telegraph".

DEVELOPMENT OF SUBMARINE TELEGRAPH

Early Attempts. Submarine telegraphy and cable telegraphy are the same as ocean cable telegraphy. Ocean cables, however, do not differ much, except in length and strength, from cables of a similar type which are sometimes laid under fresh water lakes and rivers, hence the term submarine cable has gradually come to include all kinds of cables laid under water, although sometimes fresh water cables are termed "subaqueous" to differentiate them from "submarine" or ocean cables.

As early as 1811, Sömmerring insulated a wire with india rubber and laid it across the Isar River near Munich for experimental purposes. In 1838, Pasley insulated a conductor by winding it with tarred rope and pitched yarn. He used this cable for subaqueous telegraphic purposes in connection with a Cooke-Wheatstone telegraph. In 1842, Morse laid in New York Harbor a wire insulated with hemp saturated with pitch and tar and coated with india rubber. In 1845, Cornell laid in the Hudson River twelve miles of duplex cable in which two copper conducting wires were insulated with cotton, covered with india rubber and enclosed in a lead pipe. This cable gave excellent service with Morse instruments until it was destroyed by ice in 1846.

Such accomplishments as above mentioned naturally led to serious consideration of the feasibility of laying long submarine cables in the ocean. In 1843, Morse made a proposal to the United

States Government to lay a cable across the Atlantic, but the matter was not officially considered at that time. In England, however, there was more to stimulate interest in the subject of submarine telegraphy. Telegraphic communication with Ireland and with the Continent was very much desired, and the distances as well as depth of water were comparatively not great. In 1843, gutta-percha appeared on the market and it was soon found to be an excellent material for cable insulation. In 1847, Werner Siemens invented a machine for applying a seamless coating of gutta-percha to wire, and during the next five years considerable quantities of such insulated wires were laid underground in Germany and Prussia. In 1851, the British and Irish Magnetic Telegraph Company began installing an extensive system of subterranean telegraph lines using the gutta-percha insulated wires. Armstrong laid a gutta-percha insulated cable in the Hudson River in 1848, and Siemens laid another in the harbor of Kiel. These cables indicated the superior properties of gutta-percha for cable insulation.

Dover=Calais Cables. In 1847, Messrs. Jacob and John W. Brett started a movement to construct a submarine cable across the English channel from Dover, England, to Calais, France, a distance of some twenty miles. The first Dover-Calais cable consisted of a middle section of #14 B.W.G. copper wire insulated with about one-half inch thickness of gutta-percha, and with shore ends of #16 B. W. G. wire insulated with cotton and india rubber and enclosed in lead pipe. The cable was laid August 23, 1850, but although messages were exchanged for a few hours it soon failed and the cable had to be abandoned. The next year T. R. Crampton in connection with the Brett brothers laid a second cable from Dover to Calais. It contained a core composed of four #16 B. W. G. copper wires, each insulated with gutta-percha to a thickness of approximately one-eighth inch; the four insulated conductors, being laid together with tarred hemp so as to form a solid cylindrical core, were wrapped with tarred yarn and then armored with ten #1 B. W. G. galvanized iron wire spirally wrapped about one turn for every foot of cable length. This cable gave such excellent service that its general design has become a standard type. Closely following the successful completion of the second Dover-Calais cable, many other attempts were made in different waters. After three unsuccessful efforts to connect England and Ireland, the task was satisfactorily completed, in 1853, by Charles Bright, Engineer for the Magnetic Telegraph Company. During the next five years numerous short cables were laid in European and American waters.

First Atlantic Cable. The experience gained in constructing and laying these short cables, as well as in studying the faults that developed in them, was of great value to those who later undertook to construct and lay the first Atlantic cable. It gradually became clear that, before such a long deep sea cable could be successful, it must have greater strength and better mechanical protection than had previously been provided, and that the central conductor must consist of several small wires rather than a single large wire. It was evident also that heavier machinery for laying was needed.

The idea of a transatlantic cable connecting Europe and America was not new, for besides the endeavors of Morse in 1843, Jacob Brett had, in 1845, started a company to build a transatlantic line, but serious doubts as to the possibility of successfully operating such a telegraph prevented capitalists from investing in the project. In 1854, F. N. Gisborne interested Cyrus W. Field in a proposal to connect St. Johns, Newfoundland, with the existing American land lines. Mr. Field became intensely interested not only in the Newfoundland telegraph project but also in the idea of a transatlantic cable. He obtained reports from specialists regarding the nature of the ocean bed between Ireland and Newfoundland and also regarding the probable electrical possibilities. These reports convinced him that the project could be carried out, and his unwavering faith in the ultimate success of the undertaking was an important factor in bringing it to a successful issue.

In 1856, Cyrus W. Field, John W. Brett, Charles Bright, and Edward O. W. Whitehouse made arrangements for the organization of the Atlantic Telegraph Company, which was formed to build a transatlantic cable to connect the lines of the Magnetic Telegraph Company operating in Ireland with those of the New York, Newfoundland, and London Company operating between New York and Newfoundland.

Construction of Cable. Twenty-five hundred miles of cable was manufactured with a stranded conductor made of seven #22 copper wires, surrounded with three layers of gutta-percha insulation, making a core of about 0.4 inch diameter, Fig. 4. In the deep sea section this core was bound with saturated hemp, armored with eighteen strands of iron wire and the whole given an impregnating coat of tar, pitch, and oil. The shore-end sections were made with additional insulation and a heavier armor to meet the more severe conditions.

Laying of First Cable. With the cable aboard in two approximately equal sections, one in each boat, the *Niagara* and the *Agamemnon* started to lay the first transatlantic cable from Valentia in Ireland on August 5, 1857, but after paying out over 300 miles of cable an accident occurred, due to which the cable broke and was lost. After having manufactured 700 miles more cable, a second attempt was made in June, 1858. This time the cable was joined in mid-ocean, the *Niagara* proceeded toward Newfoundland and the *Agamemnon* toward Ireland. After several minor mishaps in which over 500 miles of additional cable was lost, the laying was completed and the cable put in operation on August 5, 1858. Great were the admiration, wonder, and emotion expressed on both sides of the Atlantic by the establishment of transatlantic telegraphy, but even greater was the disappointment when, after a serious fault in the insulation had developed, the cable signals became weaker and weaker and failed altogether on September 1, 1858.

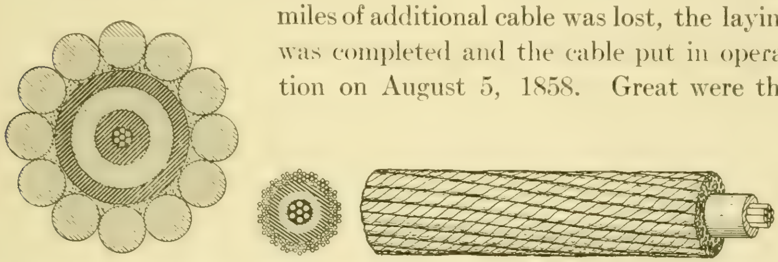


Fig. 4. Shore-End and Deep Sea Sections of First Atlantic Cable, 1858 (Shore-End Section at Left)

Failure of Cable and Its Effect. The loss occasioned by the failure of this first cable, although amounting to about two and one-quarter million dollars, was, however, not sufficient to crush Mr. Field's faith in the ultimate success of transatlantic telegraphy. He was indeed more enthusiastic for, in that brief period of fifteen days, a single one of the seven hundred thirty-two messages which had been transmitted, actually saved the British Government nearly one-quarter million dollars. Another cable message of almost immeasurable value to many persons on the other side of the Atlantic was one assuring them of the rescue of all passengers on board the *Europe* and the *Arabia,* which had been seriously damaged by collision.

Second Atlantic Cable. With the remembrance of such accomplishments in mind, Mr. Field promptly began once more to secure financial aid to enable the Atlantic Telegraph Company to lay a new cable and, if possible, to recover and restore the first one. His practical judgment led him to realize that there were many details yet to be improved in the operations of laying and repairing transatlantic cables. Accordingly very careful investigations were made as to the reasons for the various accidents and failures and of the methods and materials used in cables then being laid in the Mediterranean and the Red Seas. By 1865, preparations were completed and an attempt was made to lay the second transatlantic cable. This cable was 3.7 times as bulky and 1.8 times as heavy as the 1858 cable, hence its density was only about half that of the other. It was expected that the reduced density would make the new cable easier to lay, as the strain on the braking devices would not be so great. The lower density was due largely to the fact that the iron armor wires were wrapped with one-eighth inch thickness of Manila hemp. This, being saturated with tar, pitch, and india rubber, was wrongly expected to protect the iron wires from decay. The arrangement of the materials in this cable is shown in Fig. 5.

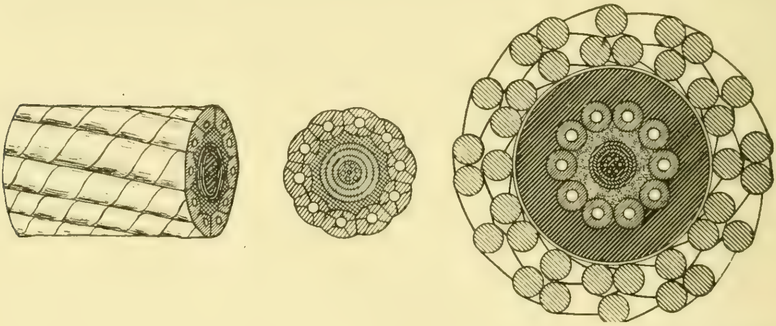


Fig. 5. Shore-End and Deep Sea Sections of Second Atlantic Cable, 1865 (Shore-End Section at Left)

Laying of Second Cable by Great Eastern. With some 2500 miles of deep sea cable, and attended by a number of ships carrying supplies and the shore-end section, the *Great Eastern* left Valentia July

23, 1865, laying the second Atlantic cable. After about 1186 miles of cable was laid, it parted and the end was lost in a depth of about 2000 fathoms. Attempts at recovery only resulted in the loss of all grappling rope and, on August 11, the officers on board gave up the attempt and started back for more cable and supplies.

Third Atlantic Cable. Even in the face of this disaster, Mr. Field did not lose faith in ultimate success, which to him seemed to be nearer than ever before; yet it was with great difficulty that he obtained further financial aid with which to carry out the undertaking. To accomplish this a new company—the Anglo-American Telegraph Company—was formed which absorbed the old Atlantic Telegraph Company. Fifteen hundred miles of additional cable was ordered, which, together with the cable on board ship, was considered sufficient to lay another cable across the Atlantic and also to repair the second, or 1865, cable. On July 13, 1866, the *Great Eastern* with 2730 miles of cable aboard began laying the third transatlantic cable. The route taken was about twenty-seven miles north of the 1865 cable. In fourteen days the western end was landed at Hearts Content, Newfoundland, and transatlantic communication was again established. Soon after, the 1865 cable was found and completed, so that on September 9, 1866, both the second and the third cables were in operation.

COMMERCIAL DEVELOPMENT OF THE TELEGRAPH

Early Companies. When on April 1, 1845, the Baltimore-Washington line was opened for public business, there was practically no business demand. The rate charged was one-fourth cent per number and during the first four days two one-number messages had been transmitted and one cent had been paid therefor. On five succeeding days the receipts were 12.5¢; 0¢; 80¢; $1.82; $1.04. It may have been partly this lack of demand that caused the United States Government to reject the proposition to purchase the telegraph for $100,000, which resulted in the formation of the Magnetic Telegraph Company, with a capitalization of $60,000 (of which $15,000 was cash), the purpose of which was to build a commercial telegraph line between Philadelphia and Fort Lee, New Jersey, opposite New York. This line was completed January 20, 1846. In June, 1846, a line was completed from Philadelphia to Baltimore.

The receipts for the first half of the year 1846, at New York, were \$223.50 and at Philadelphia \$293.17. The total receipts of the company for the year 1846 were \$4,228.77. Thus began the commercial development of land telegraphy in this country. The small group of men controlling the Morse interests soon met opposition due to the formation of other companies which proposed to operate telegraphs under other patents, particularly those of Bain and House; these were, however, eventually absorbed by the Morse interests. Those in control of the Morse patent rights had considerable trouble owing to their inability to work together, and there soon developed a large number of separate telegraph companies, each having a more or less definite relation to the original Magnetic Telegraph Company.

Western Union and Postal. In 1851, The New York and Mississippi Valley Telegraph Company and the Erie and Michigan Telegraph Company were consolidated, through the influence of Hiram Sibley and Ezra Cornell, forming the Western Union Telegraph Company. The gradual absorption by this company of practically all the important separate telegraph companies in the Middle West, has resulted in control by a single management, greatly increasing the effectiveness of the telegraph system. The monopoly thus created was later broken by the organization of the Postal Telegraph Company which, by introducing a number of changes in management as well as in equipment, became a keen competitor of the Western Union Telegraph Company.

On January 1, 1913, an agreement went into effect between the Anglo-American Cable Company and the Western Union Telegraph Company whereby the control and management of the Anglo-American cables was turned over to the Western Union Telegraph Company for a period of ninety-nine years. Thus for the first time in history the control of all transatlantic cables now lies outside of England, with the result that there is now considerable talk regarding a proposed "All British Government Telegraph" across the Atlantic, Canada, and the Pacific.

Although the Western Union Telegraph Company controls all the Anglo-American cables, there are five North Atlantic cables as well as two southern German-American cables which are operated in connection with the Postal Telegraph Company.

Besides the Atlantic cables, there is at the present time one cable across the Pacific from San Francisco to Shanghai, China, by way of Honolulu, Midway, Guam, and Manila. There is also a British cable from Vancouver to Australia, connecting thereby two older cables with the Oriental lines.

Systems Now in Use. In summing up the present status of the telegraph in America, it may be said that about 90 per cent of the entire telegraph traffic is still transmitted and received by the Morse system. There are a few lines where the amount of traffic is great, as between large cities such as New York and Chicago, St. Louis and Boston, on which the Wheatstone Automatic is used, and also a few Western Union circuits between important centers are operated by Barclay printers, but the telegraph companies in this country have not made extensive use of automatic, multiplex, or printing telegraph equipment. It is still true that a large percentage of telegraph lines are operated as single Morse circuits, although many lines are operated duplex or quadruplex. It appears that weather conditions seriously interfere with the operation of long quadruplex lines and for that reason it is often necessary to operate them duplex. With the very extensive use of the telephone today there is less tendency than formerly to send local telegrams, but on account of the expense of long distance telephony, long distance telegraphy has not been seriously affected by it. Each has its more or less distinct field of operation. The telephone and the telegraph are not in all respects competitors; they are often supplementary and co-operative.

Future Outlook. The future of the telegraph appears brighter than ever before. The telegraph was the first important practical application of electricity to the uses of mankind, but owing to the state of electrical science when the telegraph was produced, the technical developments of the system were necessarily slow, nevertheless such good progress was made that the system had advanced to a state which very satisfactorily met the demands made upon it up to about 1875. At this time the telephone, the incandescent lamp, and other electrical devices diverted the attention of many persons from efforts to improve telegraphic methods, while those in charge of the Morse telegraph maintained a practical monopoly and naturally devoted their energies to the extension of the system as it was, rather than to the introduction of new equipment. At the present time, however, the American telegraph companies are giving much more attention to improvements, and are applying modern engineering methods.

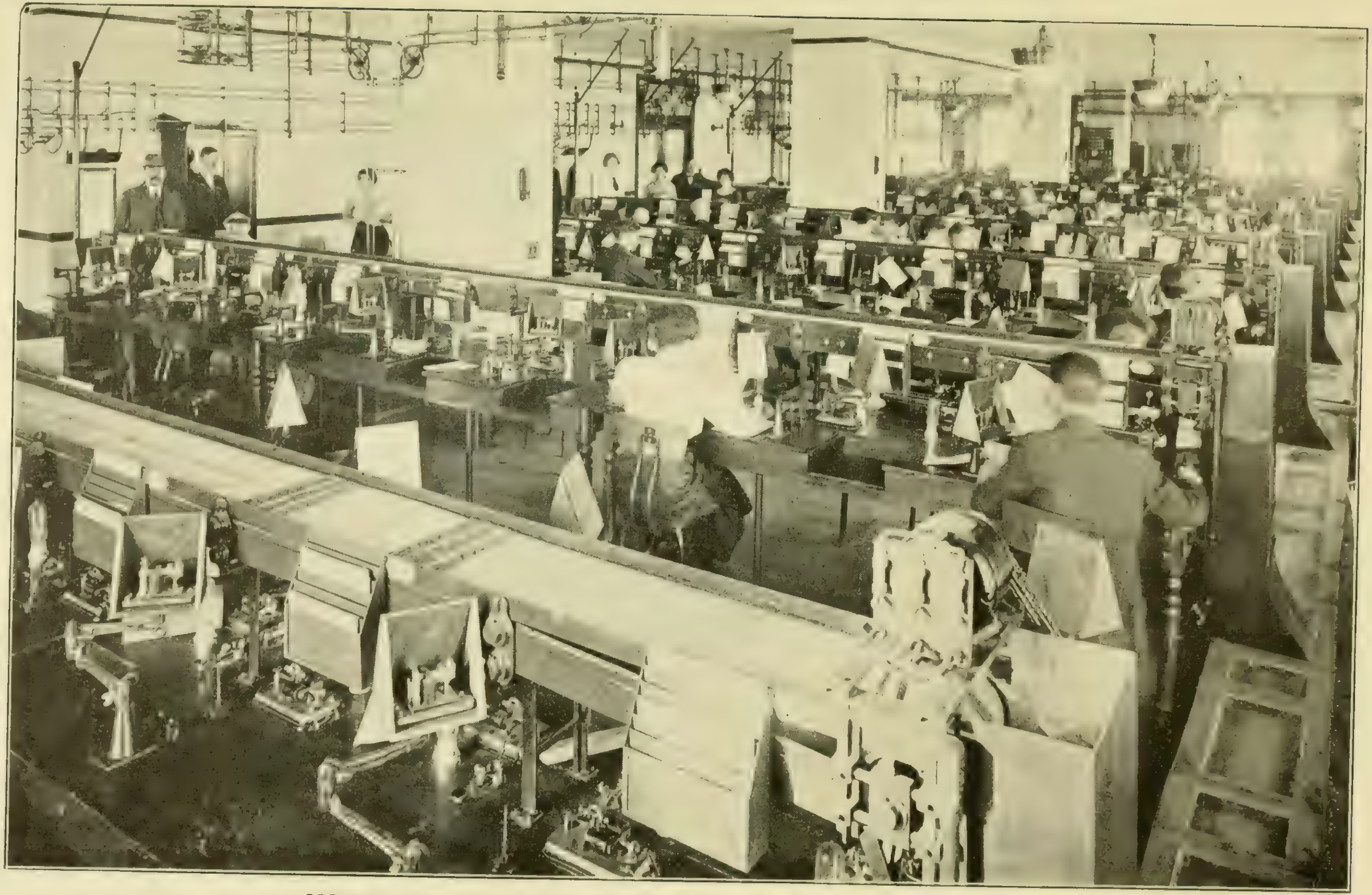
It has been thought by some that wireless telegraphy would eliminate all wire and cable telegraphs, but this is not probable unless some very radical improvements in wireless are made. The greater reliability, simplicity, and privacy of communication by wire make this system still supreme. It is possible that the common use in wireless of the Continental Morse code may, in connection with the more extended use of machine transmission, bring about the substitution of that code for the American Morse now almost exclusively used on American land lines.

Improvements to be looked for in the future include better methods of submarine cable operation, due to improved terminal equipment and better cable construction, rather than the use of either the Pupin loading coils or the Krarup type of cable. It is probable that regular cable loaded with the Pupin coils will be found more feasible than cable of the Krarup type for extensions in long distance underground cable for telephone and telegraph between important centers.

MODERN MORSE TELEGRAPHS

LAND TELEGRAPH LINE CONSTRUCTION

Structure and Characteristics. In this country practically all telegraph lines consist of either iron or copper wire supported on glass insulators attached to wood poles by means of pins and cross arms. The size and material of the conducting wire vary from small iron wire (#14 B.W.G.) for unimportant lines to large copper wire (#8 B. & S.) for important long distance lines over which automatic or quadruplex equipment is to be operated. In the United States insulators are almost invariably made of glass, while in Europe the use of porcelain insulators is common and they are also now being used in Canada. Iron wire was formerly used almost exclusively, but in later years hard drawn copper wire is extensively used because of its lower specific resistance combined with high tensile strength. The resistance of copper wire varies with temperature, purity of metal, and degree of softness of the copper. Modern



MORSE DEPARTMENT OF WESTERN UNION OFFICE, OMAHA, NEBRASKA

Courtesy of Western Union Telegraph Company

hard drawn copper has about two per cent higher specific resistance than soft annealed copper. The resistance of copper wire changes approximately one-fourth of one per cent per degree Fahrenheit*, and for this reason the temperature of a circuit should always be definitely stated or implied when accurate resistances are to be considered.

Combination Telegraph and Telephone Lines. In general the details of construction of land telegraph lines are the same as for electric telephone lines. The telegraph can transmit information over long distances at a lower cost than is possible by the telephone. At the present time the telephone has to a large extent replaced the telegraph for local distribution of intelligence, but for long distance operation the two systems are really supplementary to each other rather than competitive. Economic considerations have forced the companies to operate over the same wires and share the line expense, thus making feasible the operation of both telephone and telegraph over lines which otherwise would be commercially impossible. Consequently a large percentage of long distance telephone lines are simultaneously operated as telegraph lines by either "simplex" or "composite" methods.

Proportion of Aerial Wires and Cables. It has become necessary in modern cities and large towns to require that all electric conductors be placed underground. Long distance telephone and telegraph wires, even though they are, in the main, aerial open wire lines, are required to pass through cables at every important town, and in the aggregate such lines must therefore necessarily include considerable lengths of cable. For this reason a New York-Chicago aerial line contains about fifty miles of cable.

Underground Cable Construction. The earliest telegraph lines were laid underground, the wires being insulated by various wrappings and buried in the earth.

The construction of modern underground cable lines for either telephone or telegraph or both is economically feasible only when the traffic has become sufficiently great, the necessary density of traffic depending upon the distance and the importance of an absolutely uninterrupted service. For this reason there are relatively few long distance lines running entirely in underground cables, and these are naturally between large cities. The first modern underground cable line laid in this country was between New York and Philadelphia, a distance of about ninety miles. This has been extended until now complete underground cable connections are in regular use between Boston, Massachusetts, and Washington, D. C., a total distance of about 450 miles. Another installation of underground cable in this country is between Chicago and Milwaukee. Such underground cables are generally made with #14 B. & S. gauge copper conductors insulated with loosely wrapped paper and enclosed in a lead pipe.

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*The exact value of the temperature coefficient of resistivity of copper is 0.00428, and that of iron is 0.00625 ohm per degree centigrade, per ohm resistance at initial temperature of zero degrees centigrade.

Loaded Cable. *Pupin and Krarup Types.* Several years ago Professor Pupin found that if inductance was placed along a cable, this inductance would neutralize the effect of the distributed capacity of the cable, thereby eliminating the distortion of the signals and increasing the possible speed of transmission. His calculations showed that the use of properly designed induction coils placed at suitable distances along the line would be practically the same as though the inductances were uniformly distributed. Long distance aerial and underground installations are, therefore, equipped, wherever possible, with Pupin "loading coils"* to improve the efficiency of transmission. Thus equipped, each mile of cable shows the same loss as about ten miles of standard aerial line.

In Europe a number of installations of submarine cable have been made using a Krarup cable, which is a uniformly loaded cable, i. e., one having the inductance uniformly distributed throughout its length. As applied at present, the Pupin method is much more economical than the Krarup method. The Krarup cable, however, being uniform in size and weight, has a decided advantage for submarine use.

Subaqueous and Submarine Cables. Telephone as well as telegraph lines are not infrequently laid under rivers and bays through cables constructed very much like underground cables, although occasionally a little thicker insulation or a heavier lead sheath is applied. All such short cable is frequently termed subaqueous cable to differentiate it from the heavier and longer submarine cable. The differences in the structure of these two types of cable are due to the radically different physical conditions under which they are laid and operated. The so-called subaqueous cables are relatively short and are laid in comparatively shallow fresh water where they usually sink into the mud. Submarine, or ocean, cable is generally very long and is often laid at great depth on irregular bottoms, necessitating occasionally a span from one rocky ledge to another, and it is subject to attack from marine life and also to the corrosive action of salt water. Accidents are liable to occur and repairs are necessarily expensive, requiring considerable time during which the valuable cable equipment is out of service.

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*The Pupin "loading coil" patents are held by the American Telephone and Telegraph Company, hence in this country only Bell Telephone and Western Union Telegraph lines are equipped with loading coils.

Durability and reliability are very important factors to be considered in submarine cable construction. Another important factor is the ability of the cable to transmit telegraphic signals rapidly. This depends upon the material and dimensions of the cable. To get high-speed transmission requires a heavy and expensive cable and so the final choice is a compromise between high speed and moderate cost, determined by considerations of traffic conditions, cable characteristics, and cost.

OCEAN CABLE CONSTRUCTION

Conditions and Requirements. The costly experiences of the early days outlined in the historical section of this article conclusively showed that the structure of ocean cables must be adapted to the particular ocean bed on which they are to be laid. In mid-ocean the water is very deep, practically stationary, and uniformly at a temperature between 34 and 40 degrees Fahrenheit. Under such conditions, the chief requirements for a cable are: low electrostatic capacity, wire resistance, and leakage, compatible with the expense. The conductor and its insulation together constitute what is known as the "core" of the cable. Outside the core is the protecting armor or sheathing. It is evident that the electrical properties depend only upon the core, while the mechanical properties and tensile strength depend upon the sheathing. The same kind of core may be used for all sections of an ocean cable, but the sheathing is designed to meet conditions found on the ocean bottom. The ocean bed is largely covered with a deep layer of soft ooze into which a cable sinks and is thus well protected from accident. Some parts of the ocean bed, however, are rocky, particularly near the shore of islands or continents, where rocks and strong currents may be found which combine to wear off the armor and break the cable. For this reason, as well as because of the danger from ship anchors and fishing, shore-end sections have much heavier and stronger armor.

Core Construction. In some modern submarine cable construction the cores have been made up of a number of separately insulated conductors, as for example in the "tri-core cable" laid in 1894. Such construction has the advantage that the proportionate cost per conductor for the armor is less than in the usual form, but it also has the disadvantage that when the cable is broken three circuits are put out of service instead of one. It would be unwise for any cable company to install all of its conductors within a single sheath rather than to lay two or more separate cables, yet when other cables are also in operation multi-conductor cable may prove advantageous.

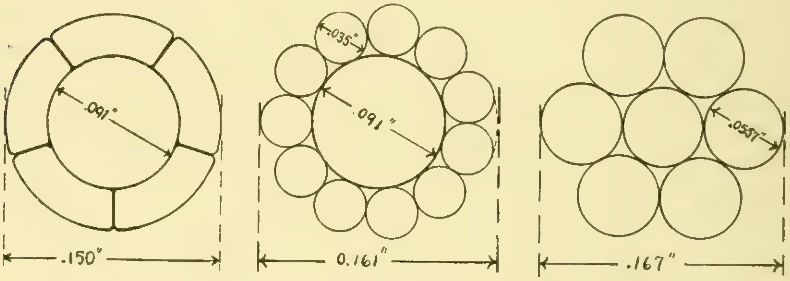


Fig. 6. Sections of Cable Showing Change in Design to Reduce Electrostatic Capacity

Methods of Reducing Electrostatic Capacity. Numerous attempts have been made to design an ocean cable with smaller electrostatic capacity without increasing the cost. The first and most successful improvement in this direction was made in 1873 by Siemens Brothers, who applied it in the direct United States cable from Brest to Halifax. It consists in replacing the conductor formed of a number of equal size wires by a conductor composed of a large wire surrounded by a ring of smaller wires. Such a group will have less diameter and hence a lower capacity than a group of equal size wires having the same aggregate cross section and therefore the same resistance. This improvement has been carried to its limit in the latest form of ribbon-stranded conductor. The reduction of diameter is clearly shown in Fig. 6 which illustrates three cable conductors having exactly the same area (0.0171 square inches): one with ribbon-wound strand of 0.150 inch diameter, one with the "Siemens solid strand" having a diameter of 0.161 inches, and the other with the regular strand of 0.167 inch diameter.

Only minor changes in cable structure have been made of late. The Krarup cable is, from the operating standpoint, a decided improvement, but its cost is altogether too high to encourage its use as a transoceanic telegraph cable.

ARTIFICIAL LINES AND CABLES

Laboratory Testing Experiments. An artificial line is an electric circuit consisting of resistors, condensers, and inductive reactors arranged in such a manner that its properties, resistance, electrostatic capacity, and inductances are the equivalent of those of the actual line which it is designed to represent. It is necessary not only that the total value of each of these properties shall be respectively equal to those of the actual line, but also that every separate portion of the circuits shall be respectively equivalent.

In practice, while the total values of resistance and of capacity of the artificial lines are very nearly equal to those of the actual line represented, the distribution of these properties is only approximately represented. The inductance of an actual telegraph line is very small and in artificial telegraph lines this factor is neglected. Artificial cables are like artificial lines except in the relative magnitude of the various properties.

TELEGRAPH EQUIPMENT

Simplex Morse System. As stated on page 15, nearly ninety per cent of all telegraph messages are now transmitted by the Morse key, using either simplex, duplex, or quadruplex methods.

The "Simplex" Morse system, also known as single line or simple Morse, makes use of one complete circuit and provides for transmission of one message at a time. It has the merit of simplicity and low cost of equipment but does not make as advantageous use of the line as methods to be described later. The equipment of a simple Morse station requires, in addition to a battery or generator for supplying current, only a sending key and a sounder, although in lines longer than about twenty miles a relay is usually included. Two different methods are used for connecting and operating Morse instruments, known respectively as the "open circuit" system and the "closed circuit" system.

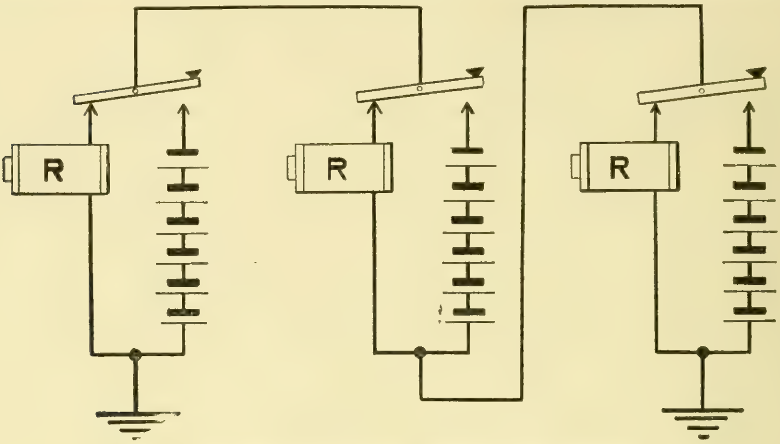


Fig. 7. European Open Circuit Telegraph Wiring Diagram

Open Circuit System. The open circuit method is shown in Fig. 7 and is the one generally used in Europe. It requires a source of current at each station, but only one battery is in operation on the line at any time. Therefore every station battery must be large

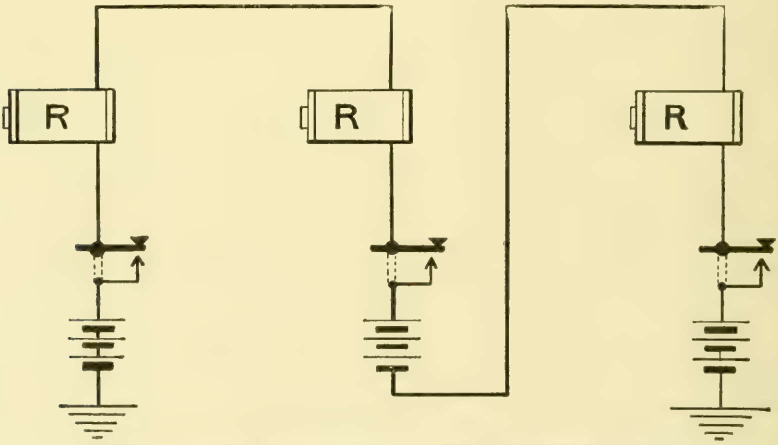


Fig. 8. American Morse Closed Circuit Telegraph Wiring Diagram

enough to supply the necessary current to operate over the entire line. When signals are not being sent, no current is on the line.

Closed Circuit System. The closed circuit method, represented in Fig. 8, is used on all Morse lines in the United States. The key is short circuited or closed by an auxiliary switch except when it is opened to send signals. Therefore, there is always current on the line.

American and Continental Morse Codes. Soon after Alfred Vail became associated with Morse, the representing of words by numbers, as mentioned in the historical section, was discontinued and a signal code was adopted in which letters and figures were represented by combinations of dots, dashes, and spaces. This code has ever since been used on all Morse lines in this country and is known as the "American Morse" code. (See Table I, page 81.)

In Europe the Wheatstone single and double needle telegraphs were early adopted and a modification of the original Morse code was devised, using combinations of dots and dashes without spaces. This became known as the "Continental" code.

Key sending is about twenty per cent more rapid by American Morse than by Continental, but in Wheatstone automatic sending there is no appreciable difference in speed by the two codes, although there is less liability of error in receiving by Continental Morse. In wireless telegraphy both codes are in use, although the Continental is more generally adopted. In submarine telegraphy the Continental is used because spaces are not accurately represented by the recorders in use, the record being a continuous wavy line.

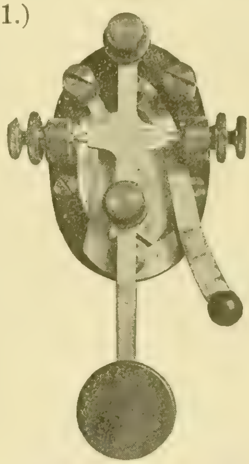


Fig. 9. Standard Morse Telegraph Key
Courtesy of Postal Telegraph-Cable Company

Telegraph Keys. The general type of telegraph key used today was originally designed by Alfred Vail about 1840. The modern key is, however, greatly improved in details, as is shown in Fig. 9. The operation of keys of this type requires an up-and-down movement of the hand involving certain muscles which eventually may become overstrained, resulting in a semi-paralysis known as telegraphers' cramp. As a result of this, some of the most experienced operators have been obliged to leave the telegraph service.

Several forms of a new type of key designed to relieve this strain have been put on the market and are now quite extensively used. One key of this semi-automatic type, shown in Fig. 10, is so designed that the key button is moved laterally instead of up and down, a change which brings into play a different set of muscles so that the particular muscles affected by operating the old type key would not be further strained. When the button of this new type key is pressed in one direction the circuit is closed, and remains closed until the pressure is released; when pressed in the opposite direction the key automatically and uniformly interrupts the current, making consecutive dots as long as this pressure continues. Such a device greatly reduces the number of movements required to send consecutive dots, or dots and dashes alternately, although it requires the same number of movements for single dots and dashes as did the old type of key. The use of these semi-automatic keys sometimes results in a very jerky style of sending, because the automatic vibrator, which makes the dots, spaces them at certain regular time intervals, and if the operator does not make the dashes of a corresponding length irregular signals will be made.

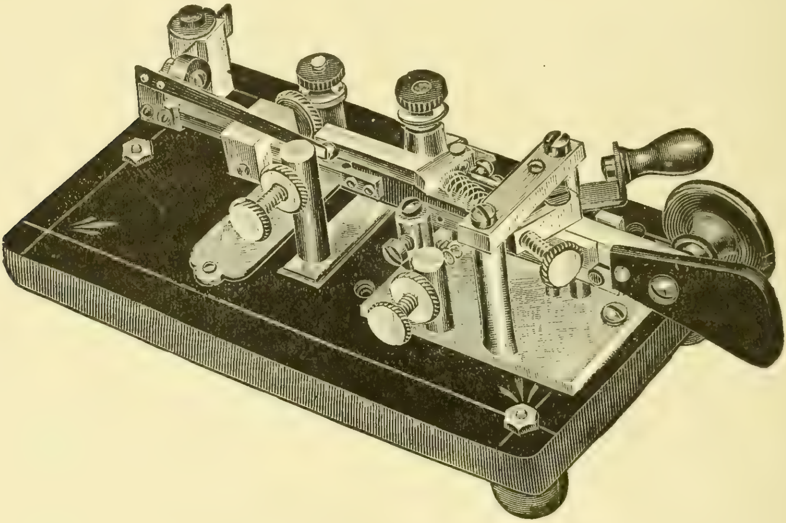


Fig. 10. Semi-Automatic "Vibroplex" Telegraph Key

Courtesy of J. E. Albricht

Sounders. The modern telegraph sounder has practically the same proportions as those of fifty years ago although the modern instrument is smaller, more conveniently adjusted, and gives a louder and clearer sound. Fig. 11 illustrates a standard sounder for use in connection with a relay. Such sounders have a resistance of 4 or 5 ohms and are usually operated with a current of about a quarter of an ampere. Sounders used on lines up to about 20 miles long have a higher resistance, often 20 ohms, due to the greater number of turns and smaller wire in the magnet winding. It is possible to make sounders with a sufficiently large number of turns

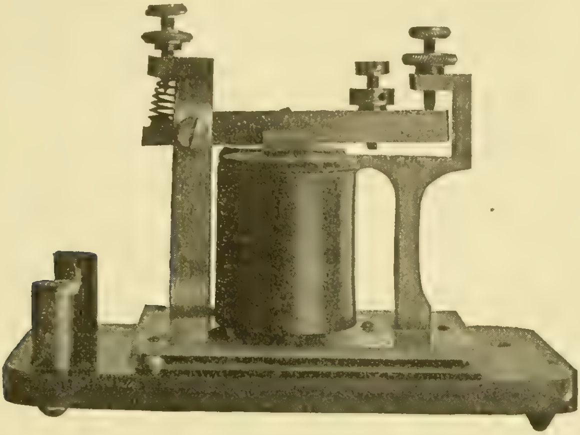


Fig. 11. Standard Morse Local Sounder
Courtesy of Postal Telegraph-Cable Company

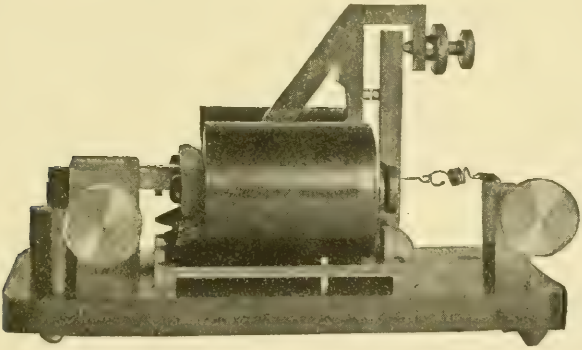


Fig. 12. Main Line Sounder with Rack and Pinion Adjustment
Courtesy of Postal Telegraph-Cable Company

on suitable magnet cores to operate directly on a long main line circuit, Fig. 12. It is more usual and better practice to make use of relays in long main lines with standard 4-ohm sounders in the local circuits.

Telegraph Relays. The purpose of a relay is to close or open a local or independent circuit automatically in such manner as to simultaneously reproduce in the new circuit the same impulses of current that are coming over the line. The relays used by Morse about 1840 weighed several hundred pounds. The modern relay, although the same in general principle, has been greatly improved in effectiveness and reduced in size. Several forms of relays are in general use. For lines less than one hundred miles pony relays may be used. These are wound with 20 to 100 ohms resistance, and have a retractile spring adjustment for the armature. For longer lines standard relays with resistance of 150 or 250 ohms are used. Fig. 13 shows a form of standard relay with the usual spring tension and adjustment for the magnet, by means of which the sensitiveness of the relay can be varied to eliminate the effects of inductive line disturbances. Standard 150-ohm relays are usually operated on circuits carrying from 30 to 75 milliamperes. Other types of relays will be considered in succeeding paragraphs.

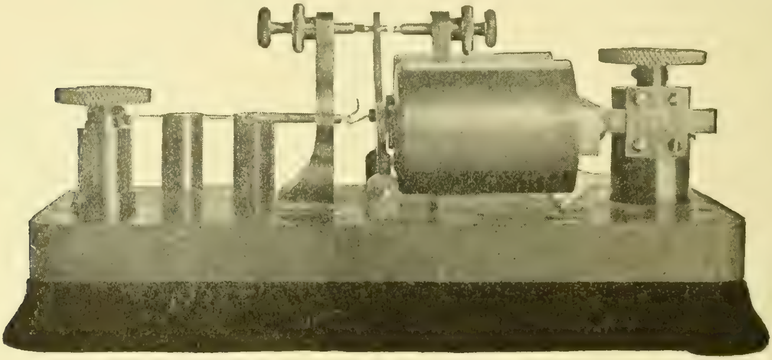


Fig. 13. Modern Morse Relay with Rack and Pinion Adjustment
Courtesy of Postal Telegraph-Cable Company

Repeaters. *Single Circuit Morse Type.* As early as 1838 Morse conceived the idea of using long telegraph lines in sections with a relay at the end of each section, through which he proposed to operate the next section, thus successively reproducing the signals which originated at the sending key of the first section. Owing to current leakage along the line the distance through which a relay will operate is limited, and for this reason, very long lines require repeating relays, Fig. 14, which re-transmit the signals with current from a local source. Morse's system of repeating will operate in one direction but not in both, unless a change of connections is made between lines and relay. Up to about 1855, the companies used for this purpose a manually-operated switch which required the attention of one operator at every repeating station.

Another way of repeating is to equip each section with a key, relay, and sounder, the operator receiving and manually repeating or relaying the message. In so doing he would close the key in the circuit of the incoming message and repeat into the outgoing circuit with the other key. To lessen the manual work, automatic repeaters were introduced, which were the same as the above in principle, being nothing more than a means of closing the circuit for incoming messages and automatically repeating the signals over the other section of the line.

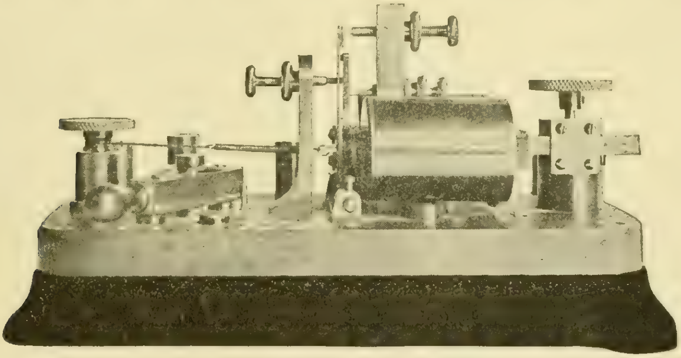


Fig. 14. Standard Morse Repeater Transmitter
Courtesy of Postal Telegraph-Cable Company

All repeater sets consist of one or more line relays and electromagnetic transmitters with auxiliary devices which hold one transmitter closed while the other is operating. The particular device by which the main line contact of the transmitter closes the circuit from one direction while the other transmitter is repeating over the other circuit, is the distinguishing feature of the different kinds of repeaters.

Weiny-Phillips Repeater. The Weiny-Phillips repeater, which has been extensively used in this country, is selected to illustrate the fundamental principles and common features of telegraph repeaters in general. The repeater set includes a repeater transmitter, which is shown in Fig. 15. This repeater operates two sets of contacts, the main line contacts being shown on a special bar at the right and the local circuit contacts at the left. A modern form of Morse repeater relay is shown in Fig. 16 in order to indicate the type.

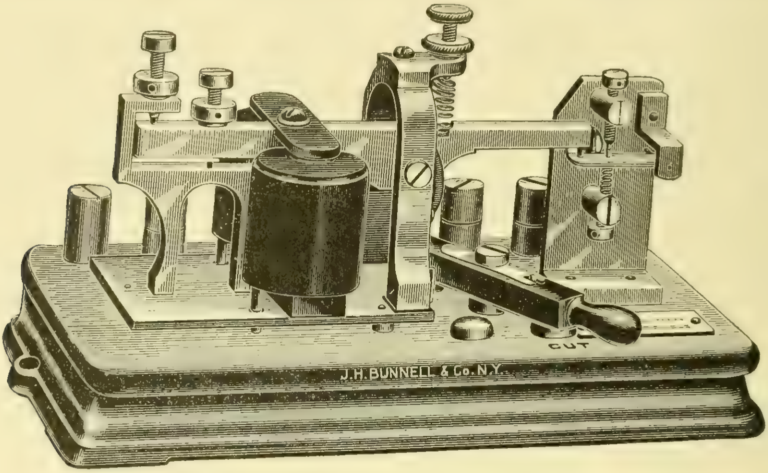


Fig. 15. Weiny-Phillips Repeater Transmitter
Courtesy of J. H. Bunnell & Company

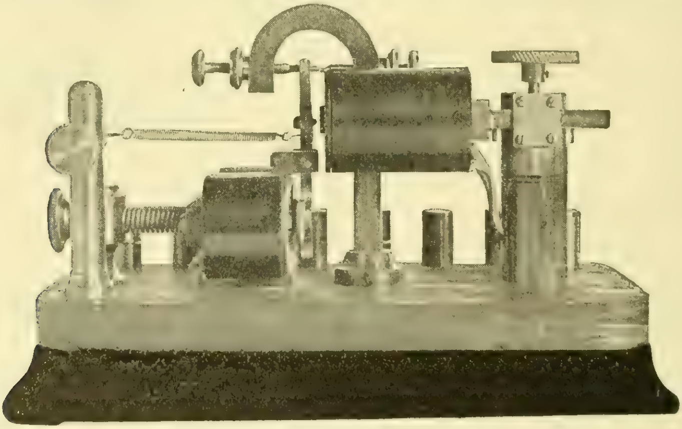


Fig. 16. Modern Morse Repeater Relay
Courtesy of Postal Telegraph-Cable Company

The lower magnet is the auxiliary or holding magnet, the armature being swiveled at the center. These magnets are respectively designated by the letters RM and HM in the circuit diagram, Fig. 17.

The operation of this repeater is made clear by means of the circuit diagram. The operator on line L has opened his key preparatory to sending a message, consequently at this instant there is no current on the line and the contact RC' of relay R is open. When signals arrive, relay R responds and operates magnet TM, thereby repeating the signals over line L' at contact C' with current from the generator. The incoming current from L, after passing through the relay coils, finds its way to contact C', and thence to ground. Contact C' must therefore remain closed, otherwise relay R would be inoperative, but it is closed only when magnet TM' is energized by relay R'. The diagram shows this condition, but it also shows that the circuit of relay magnet RM' is momentarily opened at C, as it must be between signals. How then is the contact at C'' maintained during this interval? This is accomplished by means of the supplementary or holding magnet HM', which is differentially wound with two coils and operates as follows: One terminal of local battery B' leads to the middle junction of the windings as shown. Tracing the circuits of battery B', one side is connected with switch S and the wire branches at junction J. Current flows continuously through the direct return wire to the magnet HM' and back to the

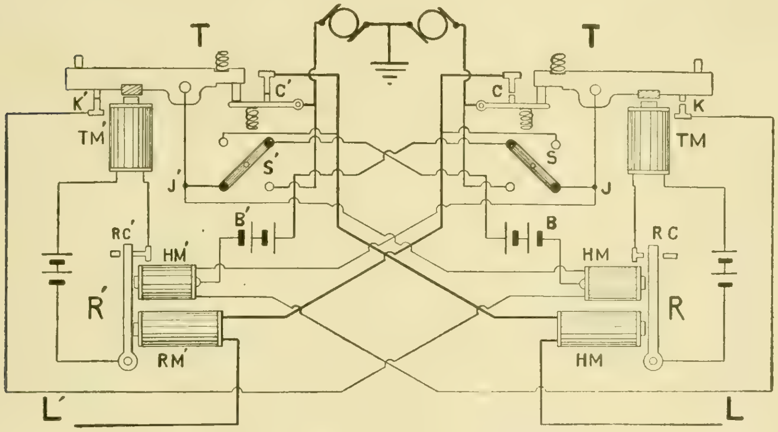


Fig. 17. Wiring Diagram for Weiny-Phillips Repeater Circuit

battery, energizing this magnet and maintaining contacts at *RC'* and *C'*. But when contact is made by the transmitter bar at *K*, another circuit is established through *HM'* which neutralizes the effect of the constant current and releases the armature; this, however, is then held by the relay magnet *RM'* and maintains continuity of line at *C'*.

Besides the Weiny-Phillips repeater there are many others, from which the following are chosen to illustrate a variety of methods which have been used for duplex operation:

Atkinson Repeater. An Atkinson repeater set includes standard repeater transmitters such as are shown in Fig. 15, standard relays, as illustrated in Fig. 13, and separate local relays, sometimes called repeating sounders.

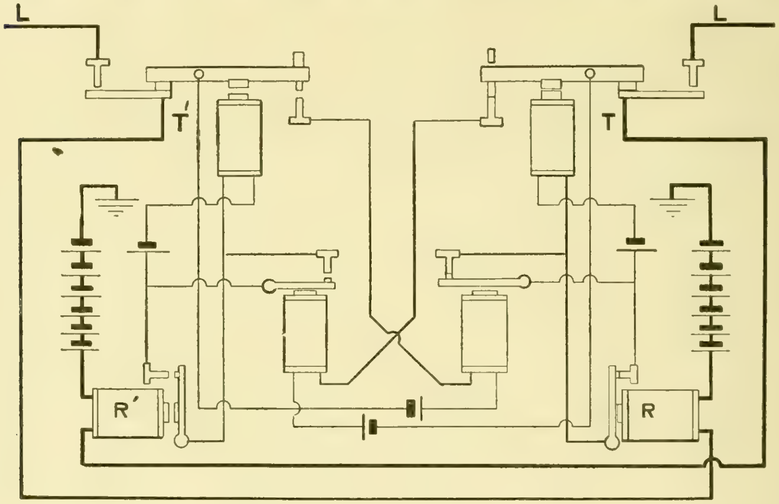


Fig. 18. Wiring Diagram for Atkinson Repeater Circuit

Instead of holding magnets on the main line relays, as in the Weiny-Phillips repeater, Atkinson uses an accessory relay which accomplishes the desired result by shunting the contact of the receiving relay, thereby maintaining current in the operating coil of the transmitter and holding its main line contacts closed under the conditions which have already been shown to be necessary for automatic repeater operation. Fig. 18 is a diagram of the circuit connections for the Atkinson repeater.

Ghegan Repeater. The Ghegan repeater set includes standard line relays of the usual type and special transmitters, each having an auxiliary armature and contacts, as shown in Fig. 19.

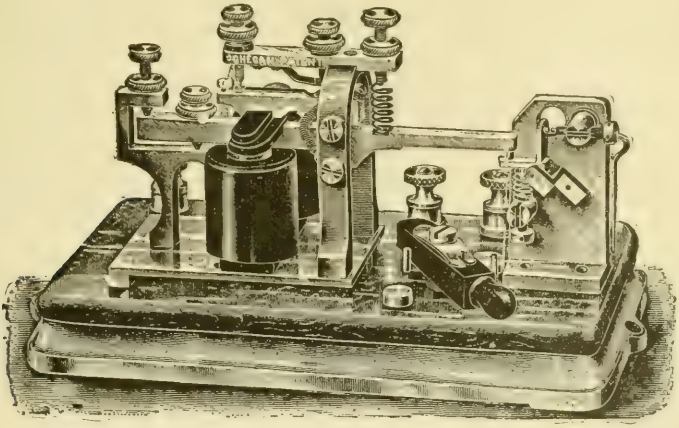


Fig. 19. Ghegan Repeater Transmitter
Courtesy of J. H. Bunnell & Company

In the Ghegan repeater set, the transmitter is held closed either by current through the contacts of the line relay or by the auxiliary armature contacts on the other transmitter which repeats the message. A diagram of the circuit connections is shown in Fig. 20.

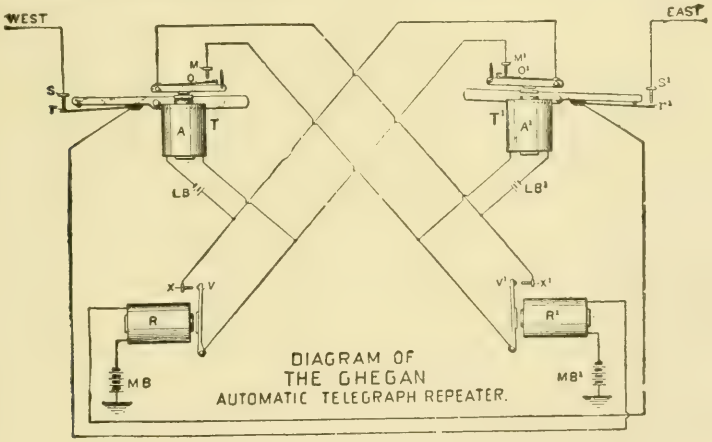


Fig. 20. Wiring Diagram for Ghegan Automatic Repeater

Milliken Repeater. The Milliken repeater set includes repeater transmitters of the type shown in Fig. 15, and a special relay having an auxiliary releasing magnet with an extra armature, to which is attached a strong retractile spring. Fig. 21 shows one of these relays, and Fig. 22 is a diagram of the circuit connections of the repeater set.

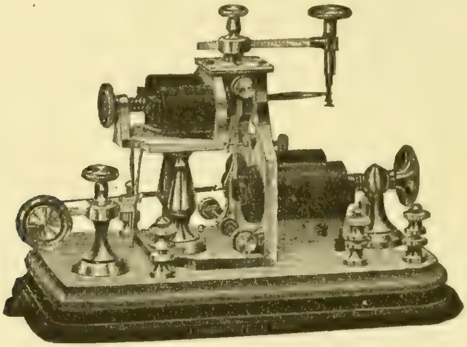


Fig. 21. Milliken Repeater Relay

The tension of the spring on the auxiliary magnet armature is adjusted so as not only to pull back the auxiliary armature but also to hold normally the armature of the main relay magnet in the closed contact position. It will be recognized that this arrangement for holding the relay contact closed is just the reverse of that used in the Weiny-Phillips repeater, the latter holding magnet and retractile spring being replaced, respectively, by the strong auxiliary spring and the auxiliary releasing magnet.

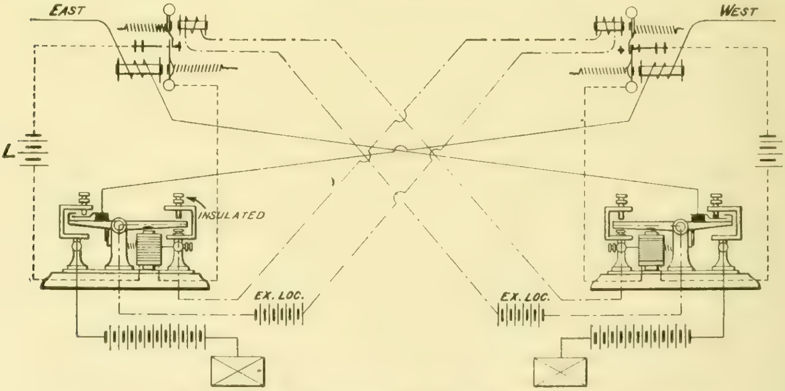
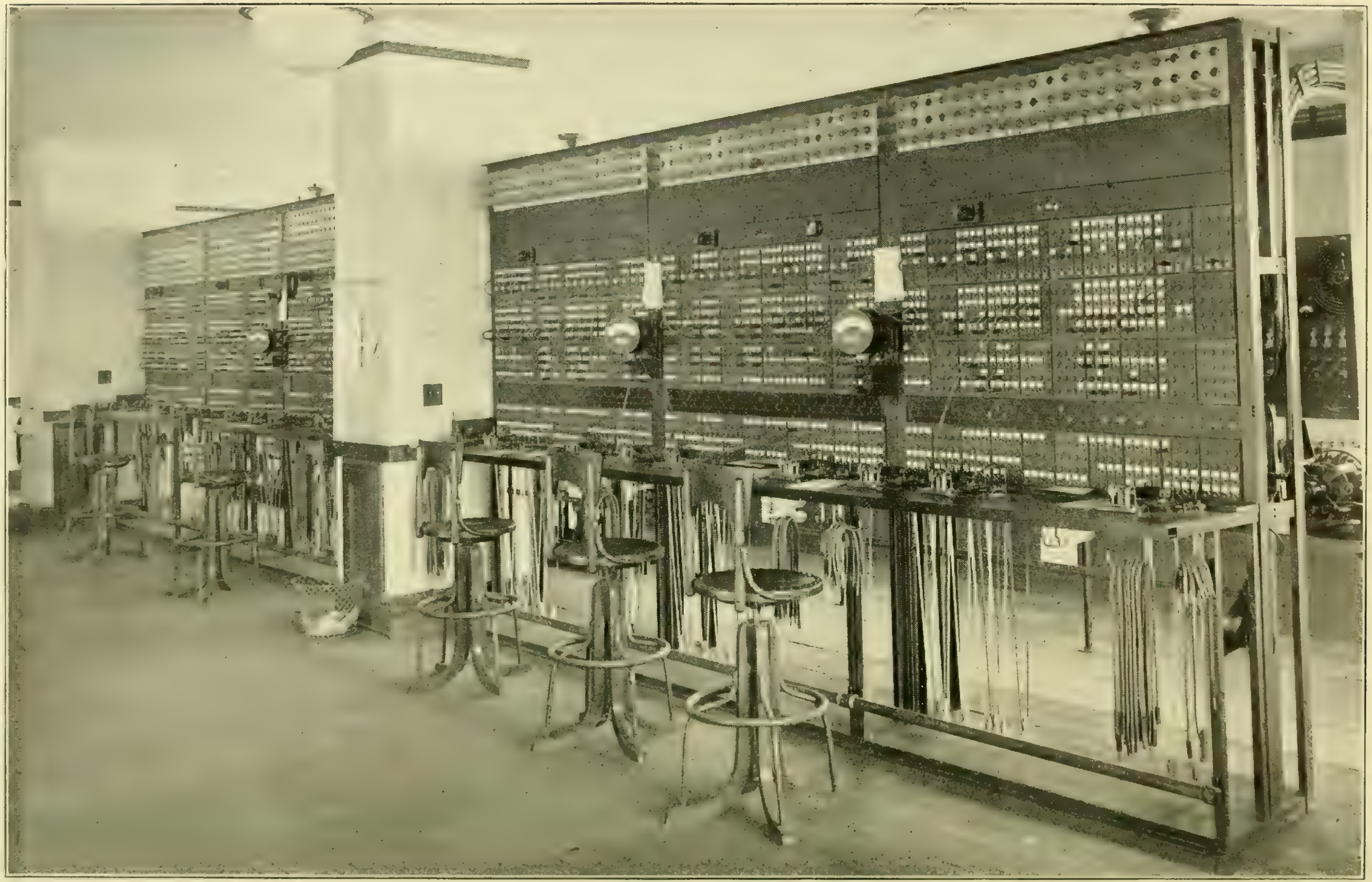


Fig. 22. Wiring Diagram of Milliken Repeater Circuits



INSTALLATION OF TEST BOARDS, WESTERN UNION OFFICE AT OMAHA, NEBRASKA

Courtesy of Western Union Telegraph Company

Toye Repeater. The Toye repeater set includes line relays of the standard type, a special repeater transmitter having front and back contacts, and an adjustable rheostat. In this repeater the contact of the receiving circuit transmitter is held closed by a current which is maintained in its winding irrespective of the position of the lever in the repeating circuit transmitter. The repeating transmitter does not break the battery circuit but instead it allows current to flow through the line relay and over the line when its operating coil is not excited, and when it is excited the circuit from battery and relay is merely shifted from the real line to an artificial line formed by the rheostat.

DUPLEX SYSTEMS

A "duplex" system of telegraphy is one by which two messages are transmitted simultaneously, one in each direction, over a single circuit.

Stearns Differential Duplex. The first duplex system extensively used was introduced about 1858, by J. B. Stearns of Boston, Massachusetts. It is sometimes designated as the single-current duplex, but is more commonly called the Stearns duplex.

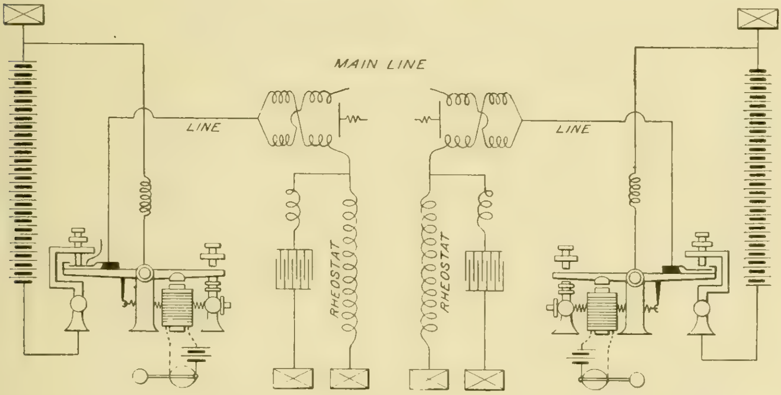


Fig. 23. Wiring Diagram of Stearns Differential Duplex Telegraph System

The characteristic feature of this system is that the relay at either station responds to incoming signals but does not respond to outgoing signals. This is accomplished by having the line relay differentially-wound and the neutral point connected to the battery and key, as shown in Fig. 23, in such a manner that current supplied from the home battery flows through both windings of the home relay, thereby producing no magnetic effect. Current coming from a distant station, however, passes through only one of the relay windings and therefore operates the relay. It is of course necessary that incoming signals be not interrupted by the operation of the home key, therefore a double contact key is necessary to ground the circuit directly when the battery is not in the circuit. This is the same as the key used in the "open circuit" single Morse line mentioned on page 22. By this method one message may be sent by the home key and another message simultaneously received by the relay and sounder without interference. In practice it is found desirable to substitute for the manually-operated open circuit type key, a magnetically-operated single-pole transmitter which reduces to a minimum the interval of time during which the line connection is being changed from battery to ground.

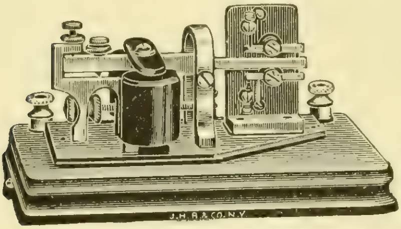


Fig. 24. Pole Changing Transmitter (B & O Pattern)
Courtesy of J. H. Bunnell & Company

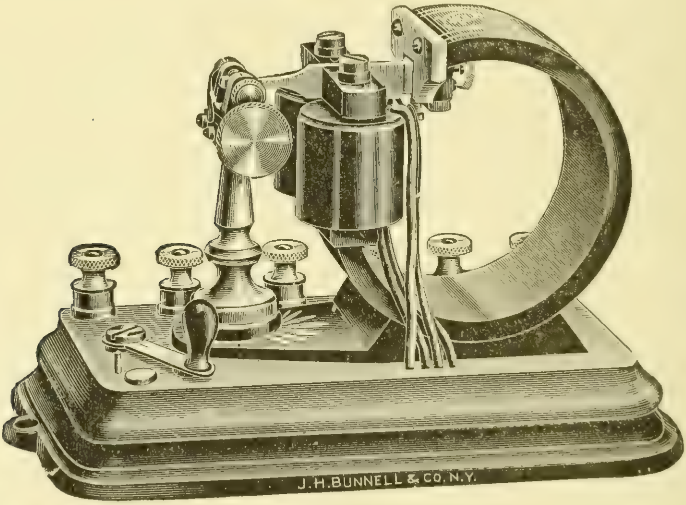

J.H.BUNNELL & CO. N.Y.

Fig. 25. Standard Polarized Relay
Courtesy of J. H. Bunnell & Company

Polar Duplex. In place of a single-pole transmitter and a non-polarized differential relay used in the Stearns duplex, a pole changer, Fig. 24, and a differentially-wound polarized relay, Fig. 25, are used in the polar duplex. The G=shaped yoke is a permanent magnet which induces magnetism constant in polarity in the small soft iron armature. The free end of the armature lies between the two soft iron poles of the relay magnet and is attracted to one pole or the other as determined by the polarity due to the last current impulse through the relay winding. As in the Stearns duplex, when the home key is operated, current is sent through both differential windings and thus no change in the magnetic condition of the core is effected. The armature does not respond to current reversals in the home circuit, but when the distant key is operated, the distant pole changer reverses the current and this reversed current, passing through only one of the windings, reverses the polarity of the relay poles and changes the armature contact.

The practical advantage of this arrangement lies in the fact that variations in the amount of current leakage from the line wire do not interfere with the operation of the relay, since this is only affected by current reversals. Operation over badly constructed lines or under adverse weather conditions is possible with the polar duplex when it would be impracticable with the single-current Stearns duplex.

Bridge Duplex. The bridge duplex derives its name from the Wheatstone bridge or balance. A double-contact or closed-circuit key, a relay, a pair of balanced resistance coils, besides the artificial line and battery, are required for the simplest bridge duplex arrangement. Fig. 26 shows a diagram of connections.

When the home relay is operated, current from the home battery is equally divided, half passing through one of the resistance coils to line and distant station, the other half passing through the other resistance coil and the artificial line to ground. The relay, which is connected as shown in the diagram, Fig. 26, will not be actuated by current from the home battery because it is connected to points having equal potentials. When current comes over the line from the distant station, however, a major portion of it will take the most direct path to ground through the relay, which therefore operates and gives the signal.

In former practice the bridge duplex was not much used but recently improved arrangements, using special inductive coils instead of the non-inductive balancing coils, have been extensively introduced as one side of a quadruplex system.

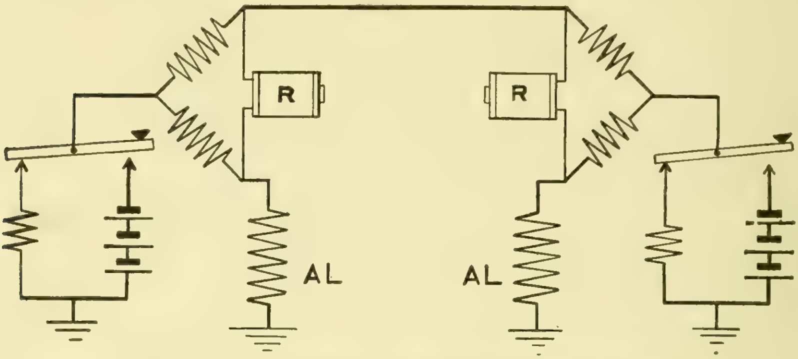


Fig. 26. Wiring Diagram of Bridge Duplex Telegraph Circuits

QUADRUPLEX SYSTEMS

Quadruplex telegraphy is a combination of duplex and diplex telegraphy whereby four messages, two in each direction, can be simultaneously transmitted over one circuit. A quadruplex set includes two differential relays, one polarized, Fig. 27, the other neutral, Fig. 28; and two transmitting keys, one of which operates a single-pole transmitter and the other a pole changer, which have

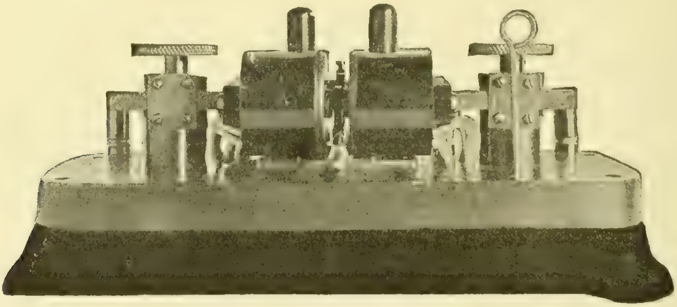


Fig. 27. Modern Polarized Relay
Courtesy of Postal Telegraph-Cable Company

already been described in connection with repeaters and duplex sets.

Method of Action. In order that a single-pole transmitter may be used in series with a pole changer on the same circuit without interference, it is necessary so to arrange that the single-pole transmitter will not reduce the line current to zero, but only to a sufficiently low value to allow the armature of the neutral relay to be released and withdrawn by its retractile spring. If this minimum value of the current is enough to operate the polar relay, it is evident that independent messages sent from the single-pole transmitter and the pole changer at one end of the line, will be received at the other end of the line by the neutral relay and the polarized relay, respectively.

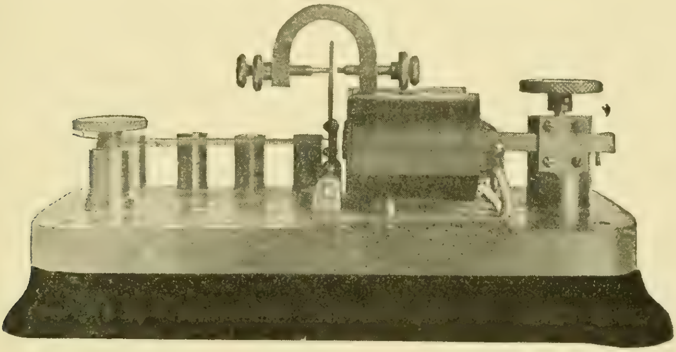


Fig. 28. Modern Quadruplex Neutral Relay with Rack and Pinion Adjustment
Courtesy of Postal Telegraph-Cable Company

Faults of Quadruplex. *Unreliability in Bad Weather.* In practice the quadruplex performs satisfactorily over good lines, but when adverse weather conditions arise, it is often necessary to discontinue quadruplex operation. This failure is due to the unreliability of the neutral side. The polar side may be operated as a duplex over a line which would not work even as a single line Morse circuit. The failure on the neutral side is due to inability to maintain at the receiving end of the line sufficient difference between the strong current and the weak current, because with increasing leakage from the line due to rain, etc., the maximum and minimum values of the received current are both reduced and the difference becomes too small to differentiate between them.

"Bugs" and "Bug Traps". Another common fault of the neutral side of a quadruplex line is known as the "bug", that is, a false signal produced by the neutral relay during the interval when the line current is changing from one polarity to another. As the current changes in polarity, the magnetism must also change and although the reversal is quickly made there is an instant when the only force acting on the relay armature is that due to the retractile spring and on this account the circuit is liable to be opened and a false signal produced.

Various devices called "bug traps" have been applied to eliminate the false signals mentioned above. Some of these are intended to be used in connection with a regular relay while others involve the use of special types of relays. One of the first methods of trapping the "bug" was by means of a local relay or repeating sounder which was connected between the neutral line relay contacts and the sounder. It is evident that although the neutral relay may weaken and its armature fall away from the front stop, if it does not reach the rear stop before being pulled back by the reversed magnetism, no false signal will be made by the receiving sounder.

Jones System. In the previous discussions of the quadruplex telegraph, it has been assumed that batteries were used and that a tap connection was made from a battery so that two voltages were available—one just sufficient to send the minimum current, the other giving full voltage for the stronger current impulses.

When current is supplied from a generator, it is impracticable to obtain the different voltages required from a single machine. In the Jones system, two pole changers and four generators are used, two giving a voltage of about 375 each, the other two a voltage of about 130 each. One terminal of a 375-volt generator connects with a contact of one pole changer, while the terminal of opposite polarity from the other generator leads to the other contact. The lower voltage generators are connected in the same manner to the other pole changer. Positive and negative currents of different voltages are thus supplied to line.

Field Key System. In the Field key system only two generators, both of the proper voltage to supply the maximum current required, are used, the lower voltage being obtained by suitable combinations of resistance coils arranged in series and in parallel. If the resistances were all in series, the resistance of the line circuit would be increased whenever the line current is to be reduced. Such changes in resistance would make it impossible to keep the artificial line balanced with the actual line.

To counteract the effect of the series resistance coils, a shunt circuit having suitable resistance is bridged across the circuit between line and ground, thus reducing the resistance of the terminal equipment by the same amount it was increased by the series resistance, and at the same time maintaining the electrical balance in the circuit.

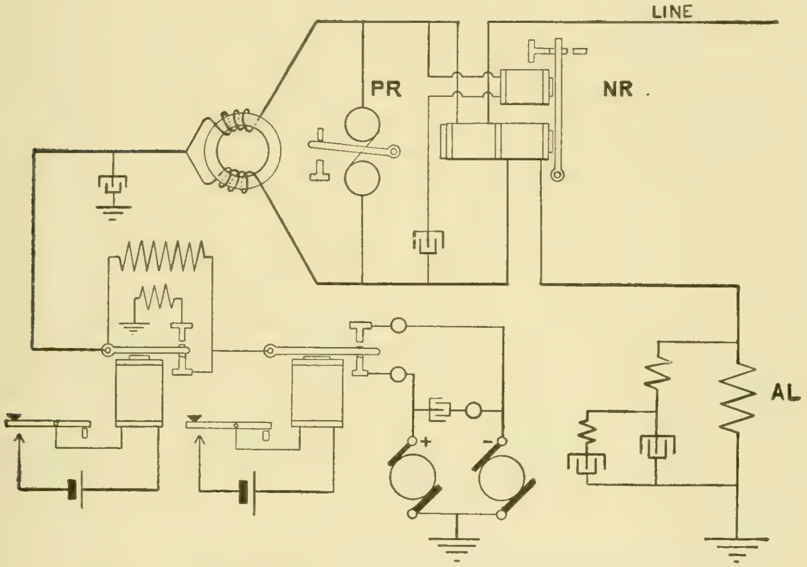


Fig. 29. Wiring Diagram of Western Union Quadruplex Telegraph Circuit

Western Union Quadruplex. The quadruplex used by the Western Union Company is a combination of the bridge and differential methods of connecting the relays to the line. The quadruplex set includes a special toroidal form of retardation coil with two balanced windings, a differentially-wound neutral relay, equipped with an auxiliary holding magnet, a Field key outfit for the neutral transmitter, a pole changing transmitter, an artificial line, and two generators. Two ends of the differential windings of the neutral relay are connected in the usual manner to the incoming line and the artificial line, as shown in Fig. 29. The other two ends of the windings are connected to the ends of the special retardation coil, between which are also bridged both the holding magnet coil of the neutral relay and the magnet coils of the polar relay.

Postal Quadruplex. A quadruplex method now used by the Postal Telegraph Company employs a simple differentially-wound neutral relay and a differentially-wound polar relay, also a pair of balanced bridge coils with a condenser across the bridge. The only circuit across the bridge is formed by a condenser, the two sides of the differential windings being respectively connected in series with the actual and the artificial line, hence this system is essentially a differential rather than a bridging system. The special feature claimed for the system is its ability to operate satisfactorily with low voltage current supply.

MULTIPLEX SYSTEMS

The sending over one wire of a larger number of messages than is possible with a quadruplex is commonly termed multiplex telegraphy. Two radically different methods have been applied.

Gray Harmonic Multiplex. The harmonic method of Elisha Gray depends upon impulses transmitted and received by the synchronous vibration of tuning forks or vibrating reeds at the two stations. A number of tuning forks are maintained in vibration by electromagnets and the vibrations interrupt the line current. The differently tuned forks send to line a complex combination of impulses representing the several tones, in other words a combination tone.

At the receiving station a number of steel ribbons or reeds, each tuned to readily respond to the vibration rate of a certain one of the tuning forks, are provided with electromagnets to cause them to vibrate with properly timed interruptions of current. By this means Morse signals sent through the contacts of any vibrating forks will be received or selected only in the circuit of the reed which vibrates at the same rate. Thus a number of messages can be sent at one time through different forks, and each will be selected by its own reed and local circuit, and recorded or read by sound. The Gray harmonic method has been recently modified and applied by Mercardier in France to the sending and receiving of twelve messages simultaneously over one wire.

Delany Multiplex Telegraph. This well-known method of multiplexing has found many applications in telegraphy. At each station there is a disk of radially-arranged segmental conductors, alternately insulated and grounded. A conducting arm or brush connected with the line rotates rapidly above the disk, making contact successively with all the segments. A number of successive insulated segments at one terminus are connected with a transmitter key; at the other terminus corresponding segments lead to a relay and sounder or recorder. It is clear that if the rotation of the brushes at the two stations is synchronous there will be a time during every revolution when the sending operator will be directly connected through these segments and the revolving brushes with the receiving apparatus. It is also obvious that a number of operators connected with other segments in the same way may have a clear line in succession. Then, if the speed of rotation of the arms, as compared with the speed of signaling, is very great, as many messages as there are groups of segments can be sent over one wire without interference. The apparatus is usually arranged for not more than six transmissions in each direction. Ingenious means are applied for maintaining synchronism of the revolving brushes.

COMBINED TELEPHONE AND TELEGRAPH TRANSMISSION

There are two general methods of telegraphing over a telephone line. Ordinarily the telephone line is a metallic circuit, although a grounded telephone circuit can be used.

Composite Telegraph and Telephone Circuit. The composite method of combining telephone and telegraph transmission usually makes use of a "metallic" or two-wire circuit for the telephone, but each of these wires is connected to the telephone through condensers, and to the telegraph through choke coils. The condensers allow the rapidly alternating telephone current to pass to the telephone, but they oppose the passage of the more steady telegraph current. The choke coils allow the telegraph current to pass through the telegraph instruments and battery to ground while they practically prevent the passage of the alternating telephone current.

Simplex Telephone and Telegraph Circuit. The simplex* method of combining telephone and telegraph transmission requires a metallic circuit for the telephone, but the telegraph circuit is formed by using both sides of the telephone circuit together as one-half of the telegraph circuit and for the other half the earth is used as a return conductor. The telegraph does not interfere with telephonic transmission because it is connected through split repeating coils or choke coils in such a manner that the influence of the telegraph current in one side of the telephone circuit is just neutralized by an equal and opposite effect in the other side of the circuit.

Another method of accomplishing the simplex operation of telephone and telegraph circuits is possible by substituting a split repeating coil for the condensers and the split choke coil, and connecting the telephone to the secondary terminals and the telegraph to the middle terminal of the primary.

PRINTING TELEGRAPHS

Classification. It will be convenient to refer to the different forms of telegraph printers under the following heads:

(1) Printers on the step-by-step principle, mostly printing on tape.

(2) Printers depending upon synchronism, in principle not strictly step-by-step machines.

(3) Printers actuated by electric signals variable in character and succession, with mechanical transmitters.

Under Division 3 we have: (a) keyboard transmission and page printing receivers; (b) automatic transmission with printing receiver apparatus; and (c) automatic transmission with tape punching receiving apparatus, the receiver tape used to operate a printing machine mechanically.

STEP-BY-STEP PRINTERS

Stock and News Tickers. *One-Wire Type.* The simplest forms of printing telegraphs are found in the different "tickers" which distribute Exchange quotations and general news, Fig. 30. These machines print letters and figures on strips of tape. They are operated on the step-by-step principle, in other words, letters arranged on the periphery of a wheel are brought successively to a printing point by means of a toothed wheel and escapement mounted on the same shaft. The shaft may be turned by a spring, a weight, or a motor with suitable gearing. The escapement is actuated by electric impulses, usually of alternating polarity, which vibrate the armature of a polarized relay. The arrangement, although much more rapid in movement, is similar to a clock escapement, the electric pulsations controlling the speed, instead of the pendulum. The type wheel of a ticker may have 26 characters and the escapement wheel half as many teeth, each electric pulsation allowing it to turn half a tooth; consequently 26 alternations are necessary for one revolution of the type wheel. It is clear that a number of such tickers can be actuated simultaneously on one wire circuit, and if all the type wheels are set in unison to print the same letter they will all turn together, half a tooth for every successive impulse.

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* The term "simplex" is used in two different ways. A simple single-circuit Morse telegraph line is said to be a simplex line to distinguish it from a duplex or multiplex.

The simplex method of simultaneously transmitting telephone and telegraph messages is quite different. It is generally easy to learn which meaning is intended from the context.

The operator at a transmitting keyboard sends to line the alternations of current necessary to bring any desired letter opposite the printing point, when the type wheel stops. The alternations of current pass through the polarized relay operating the escapement as described, and they also pass through an electromagnet, the armature of which actuates a lever that forces the printing platen against the letter and impresses the mark upon the intervening tape. Because of its inertia the printing armature does not respond to the rapid pulsations of current which move the type wheel, but when the transmitter ceases to send alternations and the type wheel stops, a stronger current flows which causes the printing magnet to operate.

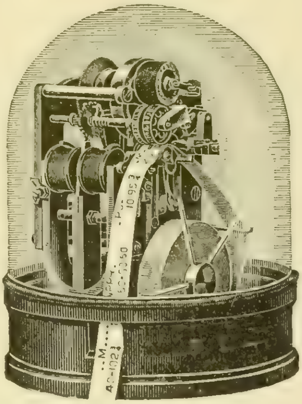


Fig. 30. Burry General News Ticker
Courtesy of Stock Quotation Telegraph Company

When a considerable number of tickers are operated on one circuit, or from one transmitter, it is necessary occasionally to interrupt the sending to make sure that all are working in unison. This is usually effected by some device which causes the wheels to make two or three revolutions and stop at the same printing point. In the ticker of the New York Quotation Company, which is the Stock

Exchange Ticker, the unison of the type wheels is automatically insured with every revolution, a matter of considerable importance since printing can thus go on continuously without the occasional losses of time in maintaining synchronism. The excellence of this ticker and many features pertaining to its mechanism are largely due to the inventive genius of Clarence L. Healy.

Two-Wire Type. We have indicated the principle of the simplest one-wire ticker, with a single type wheel. Most tickers in use have two type wheels, one for letters and another for figures and other characters. Various devices are arranged to shift either the two wheels on their shaft, or the printing platen, thus printing figures or letters as desired. In two-wire tickers the second wire is commonly used with two-type-wheel machines for the shifting, although a single wire can be made to operate a two-wheel ticker, as the Phelps for example.

Edison Ticker. The step-by-step movement in the Edison ticker, a two-wire printer, is effected directly by the transmission pulsations which actuate the armature of a magnet. The armature carries two arms, curving around a gear wheel on the shaft and bearing teeth which engage on opposite sides of the gear in such manner that the moving armature alternately pushes and pulls on the gear and thus turns the shaft.

Step-by-step tickers afford good service but are too slow in operation for the general telegraph service and not well adapted for use on long lines, being usually operated in series, on metallic circuits. Long distance printers are of many forms and degrees of complexity, most of them printing on tape, which is inconvenient in many ways, others delivering printed messages on sheets like typewritten copy.

House Printing Telegraph. The first printing telegraph intended for general long distance working was patented by Royal E. House, of Vermont, in 1846. It was introduced commercially on the New York-Philadelphia line in March, 1849, and its use rapidly extended during the following ten years. It is a step-by-step device, operated from a keyboard and is reputed to have sent repeatedly 2600 words an hour. On one occasion the annual message of the Governor of New York containing 5000 words was transmitted by this instrument and published in New York two hours after its delivery in Albany.

Burry Page Printer. The Burry Page Printer, Fig. 31, is most widely used for general news ticker service. It was introduced about 1891, and is now put out by the Stock Quotation Telegraph Company and used by the New York News Bureau.

Transmission is from a keyboard with the keys arranged in a circle. The type wheel travels across the paper, which is in a roll $5\frac{1}{2}$ inches in width, and is returned to begin a new line at the will of the operator. It is controlled by a magnetic escapement. A notable feature of this apparatus is the manner of turning the type wheel to select a letter. A single pulsation of the magnet permits the escapement wheel to turn one tooth. This movement is equivalent to the space of two letters on the type wheel. Thus the escapement wheel brings the type wheel to an approximate position for printing, with the printing point between two letters. When it is desired to print either of these letters, a star wheel on the shaft is turned by a magnet actuating a V-shaped tooth which engages between two teeth of the star wheel. By this means the type wheel is turned $\frac{1}{72}$ of a revolution either one way or the other to bring the desired letter to the printing point.

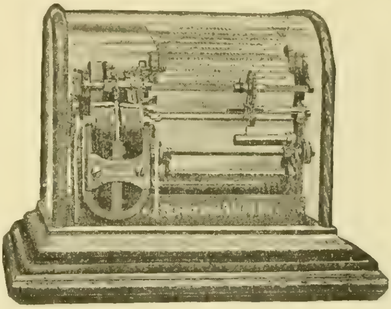


Fig. 31. Burry Page Printer
Courtesy of Stock Quotation Telegraph Company

The motive power consists of springs which are automatically wound by magnets as the printing goes on. The inventor is John Burry.

Dow, Jones and Company Electric Page Printer. The Dow-Jones Page Printer has been long in use as a general news ticker, but recently some improvements have been introduced and patented by George S. Conger. It is much used on telephone lines and works well through cables from New York to Brooklyn with current limited to 0.3 ampere.

The type wheel escapement magnet is in the line circuit, but the operations of printing, spacing, moving paper, and winding of the spring which revolves the type wheel shaft, are all done by local battery power controlled by two pony relays in the line, which are respectively responsive to currents of opposite polarities but are not sensitive to the rapid alternations of current that actuate the escapement magnet. As in the Burry Page Printer the type wheel moves across the paper. Synchronism is secured in the usual way by allowing the type wheel to make two or three successive revolutions and come to the unison stop.

PRINTERS DEPENDING UPON SYNCHRONISM

Hughes Printing Telegraph. The Hughes telegraph was invented by David E. Hughes, of Kentucky, in 1855, and improved by the co-operation of George M. Phelps, of Vermont, well known in connection with later printing telegraph inventions. It was first used commercially between Worcester and Springfield, Massachusetts, and between New York and Boston, in 1856. In this country it gave way to other forms of printing machines, but in England and on the Continent it is still largely used, sending from 35 to 40 words a minute with remarkable accuracy. Up to about 1874, most of the telegraphic business of the Western Union between New York and Boston, Philadelphia and Washington was done by printing telegraphs developed by American inventors, but all have been discarded in favor of Morse methods.

Principle of Action. The Hughes Printing Telegraph has a keyboard similar in appearance to a piano keyboard, with 28 keys. It is run either by a weight or motor and prints both letters and figures on tape. A horizontally revolving "chariot" is carried on a vertical shaft which is geared to the horizontal axis of a type wheel and these necessarily revolve together synchronously. When a key is depressed it raises a pin beneath the chariot and, as the chariot revolves, a contact is made with the pin and a single electric impulse is sent to line. This is the only electrical action of the apparatus—one impulse prints a letter. All other operations are mechanical.

Transmitting and Receiving. The same machine is used for sending and receiving. The synchronism of machines at different stations is secured at starting by adjustment by the receiving operator, while the sender transmits test signals, after which they run regularly save for slight irregularities which are corrected by an ingenious mechanism brought into action by the printing current.

The printing cam is actuated by the release of the armature of a Hughes magnet in the line circuit. The chariot makes contact for each letter at the instant when the letter on the type wheel faces the printing cam. Therefore, the contact is independent of the time of depressing a key. Since the chariot cannot send letters in indiscriminate order in one revolution, the operator must be experienced in working the keys.

The type wheel revolves continuously with the shaft and is not stopped for the printing operation. It is not rigidly secured to the shaft, however, but is capable of being slightly accelerated or retarded, or even stopped, while the shaft continues running.

Method of Providing Synchronism. The printing current actuates a printing shaft which carries the printing cam, a correcting cam, and a cam for moving the tape. The correcting cam comes into action with each revolution of the printing axis, in other words, with each line impulse, and while it is difficult to describe its operation in few words, the principle of its action is that the cam fits exactly between the teeth of a correcting wheel on the type wheel shaft and if the latter is not exactly in unison its motion is slightly hastened or retarded by the action of the cam.

American Combination Printing Telegraph. The American Combination Printing Telegraph was the outcome of improvements made by Phelps on the Hughes invention. It was perfected in 1859, and afforded good service on different lines for many years. The continuously moving type wheel of the Hughes machine was retained and also the keyboard, but instead of the somewhat complicated and comparatively slow "chariot" of the Hughes, a rapidly revolving cylinder made the line signals much more quickly.

Phelps Motor Printer. The Phelps Motor Printer was introduced in 1875, and represented a considerable advance over its predecessors, partly because of its stronger construction which permitted of more rapid work and because of the use of an electric motor. The Hughes keyboard has been retained and the general principle of operation is much the same, except that the type wheel does not run continuously. The mechanism also differs from the Hughes.

Method of Action. The speed of the motors at different stations is controlled by a special form of governor. As the motors run independently of each other synchronism must be established by the operators when beginning to operate. As in the Hughes apparatus, a detent attachment acting upon a toothed wheel every time a printing current is received, ensures synchronism between the type wheel and the transmitting ring which makes the printing contact. The turning of the type wheel is arrested after every revolution. The printing magnet is operated when the desired letter is opposite the printing point. The speed of working is given as 65 to 75 words a minute.

Use on Quadruplex Circuits. This printer has been used on quadruplex circuits, the polar side being utilized for transmitting messages while the neutral side serves for "breaks". If quadruplex circuits can be advantageously utilized in this way it is clear that considerably more business can be done with duplexed printers than with quadruplexed Morse.

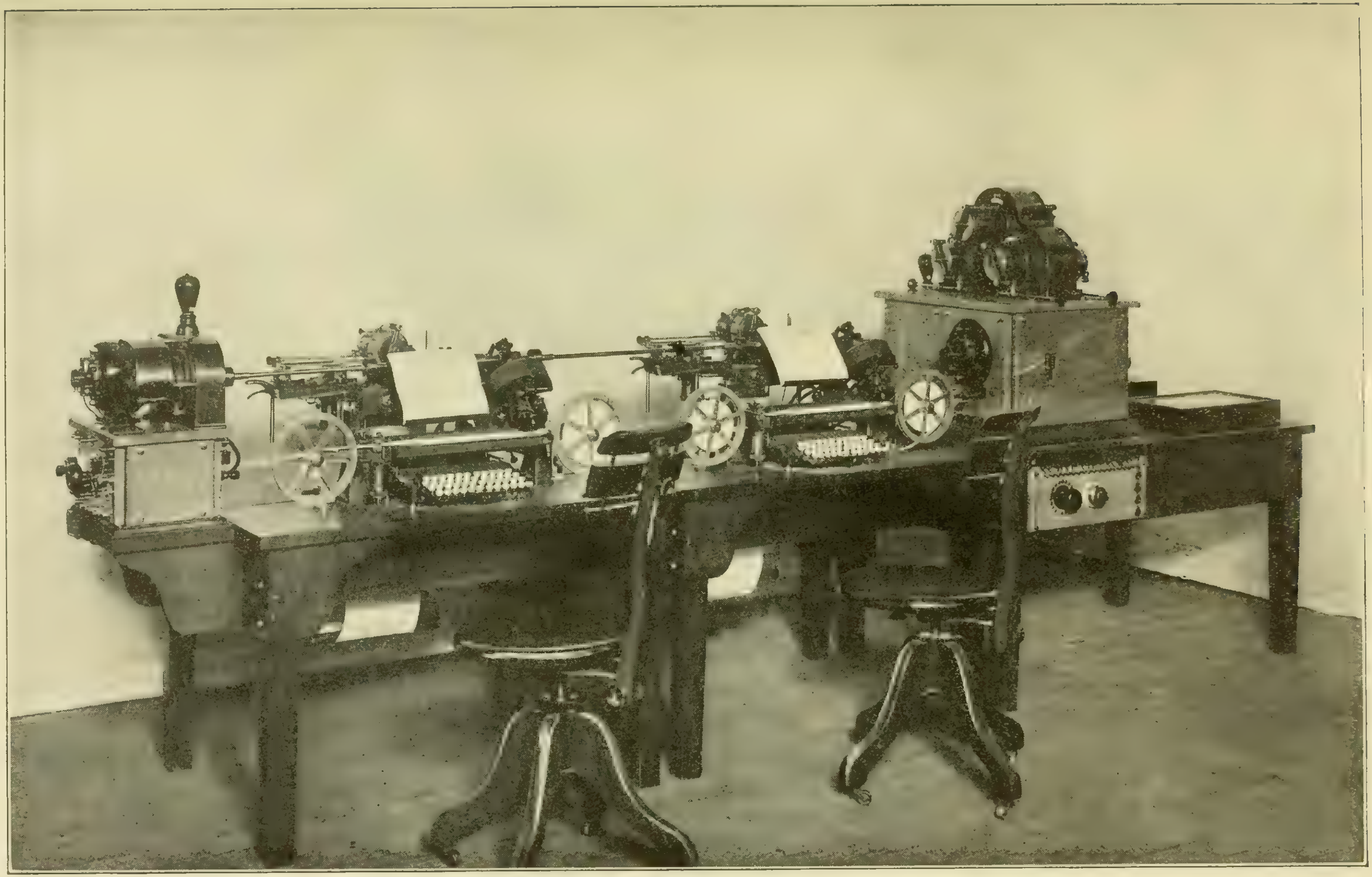
Baudot Multiplex Printer. The Baudot Multiplex Printer is largely used in France and Italy, and elsewhere on the Continent. Messages are printed on tape from a type wheel at a speed of about three letters per second, but six messages may be transmitted simultaneously on one wire by synchronous multiplexing.

Method of Multiplexing. The line is multiplexed by a segmental disk and revolving trailer, practically the same as has already been described under "Multiplex Telegraphy" (page 41). If different machines are sending at the same time, each has control of the wire in turn and is able to send one letter as the trailer makes one revolution.

The transmitter has five keys each directly connected electrically with one of the five successive segments of the disk. Five impulses are transmitted for each letter. Normally all the keys send negative currents to line. The depression of any key sends a positive current, but a negative flows through contacts of the other keys. With five keys, 32 different combinations are possible. The operator depresses one or more keys, thus initiating the necessary combination for transmission. While the keys are held down the trailer sends out the succession of polarities of the combination. The operator receives a signal when the trailer has passed and then prepares for the next letter.

The trailer at the distant station passing the corresponding segments is connected with a polarized relay, and the received currents energize successively one or more of five magnets which bring mechanism into action to print the proper letter, move the tape, etc.

Spacing Between Words. A later improvement includes a sixth sector which sends a supplementary current, almost simultaneously



FRONT VIEW OF ROWLAND STANDARD QUADRUPLEX TELEGRAPH INSTRUMENT
Line-Unit on Table at Right; Two Correspondence-Units on Table at Left. This Photograph Serves to Show Transmitter and Home Recorder.

with the final letter of a word, which effects spacing between words. This increases the operating speed, but the writer is unable to learn that it has been utilized in service.

Rowland Multiplex Printing Telegraph. This highly developed and ingenious page printer is the invention of the late Professor Henry A. Rowland, of Johns Hopkins University. It is doubtless the most perfect and efficient long distance printer, since eight separate printing transmissions can be effected simultaneously over one wire. The transmitter has a keyboard like a typewriter, but the keys are mechanically held while signaling, thus reducing somewhat the practicable speed to from 30 to 35 words a minute. The printer is under control of the sender, the depression of a key at any moment bringing the carriage back for a new line or causing a drop directly to a new line at any point.

It is impossible properly to describe the mechanical features of this apparatus in the space here available, but the electrical principles of transmission and synchronism deserve more than casual mention.

Maintenance of Synchronism. Alternating current is used and synchronism is maintained by the use of every impulse sent over the wire in octoplex, operating 196 a second. The tongue of the main line relay vibrates with the alternations from the distant station. A brush driven by a motor passes over a commutator with alternate segments connected electrically, the number of these segments being such that each segment corresponds to a half wave of the alternating current used for signaling. The alternate segments are connected with the two contacts of the tongue of the line relay. With the relay tongue on one of its contacts a resistance is introduced in series with the armature of the motor and less current flows, but on the other contact the resistance is shunted. As the relay tongue is constantly vibrating, the variations in current in the armature in addition to the regular current, maintain the speed of the motor constant; that is, if the rate of vibration of the relay increases, more current flows through the armature and the speed of the motor will increase, but only until it corresponds to the relay tongue vibrations. If the motor tends to run slower or faster than the relay vibrations, the armature current is increased or lessened and the speed is thus maintained constant. In this manner a change in voltage on the line which would otherwise cause a motor speed variation of 50 per cent, does not cause loss of synchronism.

Signaling Current. The same current is used for signaling and for synchronizing. The alternations, at a normal speed of 98 cycles a second, are sent over the line continuously. A block of 56 successive half waves is subdivided into 4 blocks of 14 half waves each, and each of these sets of 14 half waves is assigned to a different operator, affording 4 transmissions each way if duplexed. But only 11 half waves are used in printing, the 3 others being utilized for other purposes. The printing of a letter is effected by the reversal of 2 of the 11 half waves. This permits of 55 different printing signals, of which only 51 are used. Each operator has his block 3.5 times a second.

Transmitting Apparatus. The transmitting apparatus consists of a keyboard, a sending commutator, and a transmitting relay. The commutator ring is divided into 56 segments, 11 segments for each keyboard. Each segment corresponds to a half wave. When a key is depressed, it connects 2 of the 11 segments with the negative. The transmitting polar relay tongue is normally held against one of its contacts, but when a key is depressed, and the brush passes the commutator segments made negative by the key, the relay tongue passes to the other contact and sends a reverse impulse to line.

Receiving and Printing Apparatus. At the receiving station there is a line relay which constantly vibrates with the alternations received from the transmitter. This relay has two independent tongues, one for synchronizing, the other for printing. Since the printing is done by selecting 2 out of the 11 pulses, there are 11 polarized relays each connected with a segment of a commutator like the commutator at the sending station, with 56 segments. The relays are connected alternately in reverse, consequently each is against its back-stop unless a reversed current brings it over to the opposite contact. This arrangement, therefore, reverses two of the relay tongues when the two reversed pulses are received.

Each of these relays, as it responds to a reversal of current, establishes a circuit through corresponding segments of a combination commutator having three rings, whereby a print relay is energized, which closes the circuit of the print magnet, and prints the proper letter. The function of the combination relay in selecting the required letter cannot be easily made clear without considerable explanation, but an effort has been made to indicate the method of synchronizing and wave signaling, and how the two reversals are utilized up to this point.

The 2 reversals out of 11 waves permit of 51 operations under control of the sending operator. All the operations common to typewriters are done with precision from the sending keyboard, and some other operations besides.

The Rowland Printer has been operated on regular business in octoplex by the Postal Telegraph Company. The reasons for its abandonment are not very clear, but they are certainly not to be attributed to any failure of the apparatus, for it is doing excellent service in Italy and seems to have demonstrated in a large way a far greater telegraphic efficiency than the Baudot printer which has long been used in that country.

Siemens=Halske Rapid Printing Telegraph. In 1894, a Schnellwirkender Typendruck Telegraph was described by William Siemens, which is remarkable for the means of effecting synchronism and the speed of printing. It is a tape sending machine, the tape being prepared by a keyboard perforator with a beautifully complex arrangement of holes. As in the Hughes printer, there are two synchronously revolving disks, one at each end of the line, and since these rotate at a speed of 2000 revolutions a minute and a letter may be printed each revolution, they must move rather well together if the right letter is to be printed. The letters are perforated around the margin of the revolving disk of the receiver and during the small fraction of a second of time any given letter is passing the printing point, it is illuminated by a powerful electric spark and photographically printed on sensitized paper.

The printing of 2000 letters—400 to 500 words—a minute is a considerable achievement, and it is stated that this apparatus has been shown to be commercially practicable by use on telegraph lines.

PRINTERS WITH ELECTRIC SIGNALS AND MECHANICAL TRANSMITTERS

Keyboard Page Printers

The first commercially introduced page printer was devised by John E. Wright, of New York, for ticker service. It was introduced by the Column News Company, of London, about 1888, and later found considerable application on the Continent. This was a step-by-step machine which worked at a speed of 20 to 25 words a minute.

For many years inventors have endeavored to perfect a page printing telegraph sufficiently rapid and reliable for general telegraph use on long lines, but owing to the difficulties to be overcome progress in this direction has been slow. We can only briefly refer to some of the later developments in this line, since a satisfactory, intelligible description of the diverse mechanical and electrical features of different inventors would require too much space.

Wright Page Printer. This machine was brought forward some time ago under the name of the Telegraphic Typewriter. It was invented by John E. Wright and represents a radical departure from any apparatus mentioned in that it is not properly a step-by-step machine and there is no synchronism involved.

Transmitter and Receiver. The transmitter has a standard typewriter keyboard, the keys are free, and it may be operated by any typist at fast typewriter speed. It can be duplexed, or a number of printers can be operated from one transmitter on a single wire. The receiver is a specially designed page printer, with letters on a type wheel having vertical movement as well as turning with the upright shaft. The different letters are brought to the printing point by magnets controlled by the line transmission. The mechanical movements are made by motor power.

Method of Action. The transmission is from an intermittently revolving commutator controlled by the key movements, which sends to line the particular succession of signals, long and short and of changing polarity, necessary to print the desired letter. The average number of impulses for printing is three and a half, but the least used character requires eight. This machine was for some time used on wires of the Associated Press in New York City and was also well tested by the Postal Telegraph Company. However, the present form of the Wright apparatus differs in important features from the machines here mentioned and presumably represents a more perfect stage of development. The details of the later improvements are not available for publication at this time.

Morkrum Printing Telegraph. The Morkrum Telegraph, the keyboard transmitter of which is shown in Fig. 32, is the latest form of keyboard printer and represents a distinct advance in the art.

It is now in operation duplexed on several lines of the Postal Telegraph Company, the Western Union Telegraph Company, and several railroads.

Six unit time intervals of current are used in transmission for each letter, first the starting interval, always of positive polarity, the other five, by reversals of polarity, permitting of 32 combinations. By use of the type wheel shift 53 characters may be printed.

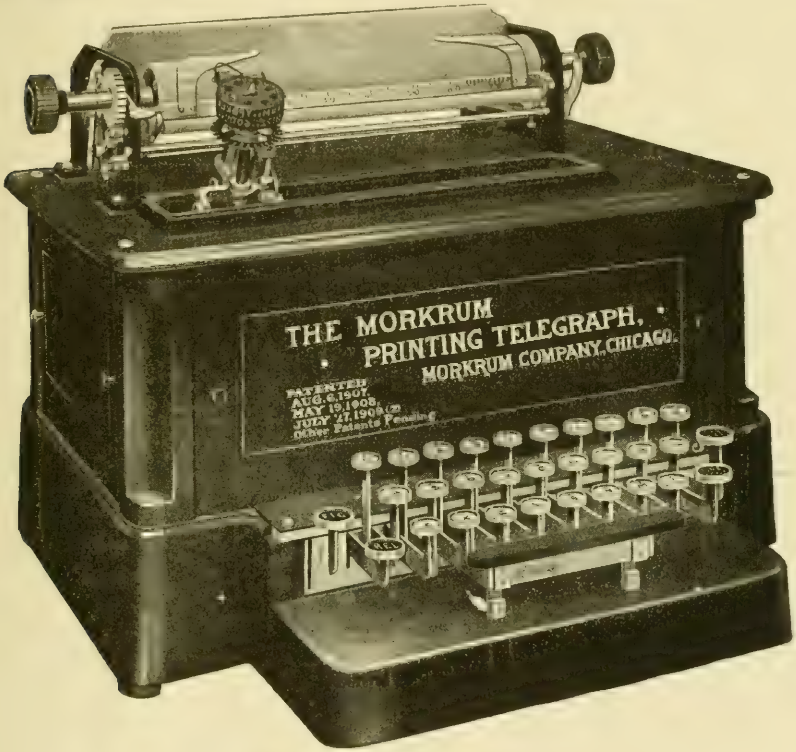


Fig. 32. Morkrum Telegraph Keyboard Transmitter
Courtesy of Morkrum Company

Method of Signaling. The wiring diagram for the complete circuit is shown in Fig. 33. Normally negative current is on the line. Signals are sent by reversals of polarity, the line impulses varying in length by full units. While the number of signaling impulses averages only two for each letter, never exceeding three, the time required for printing a letter is uniformly equal to the six unit intervals. This, however, permits sufficiently rapid work with the keyboard.

The signaling combinations are made by five keyboard pole changers and a commutator connecting them in successive order with the transmitting line relay or pole changer.

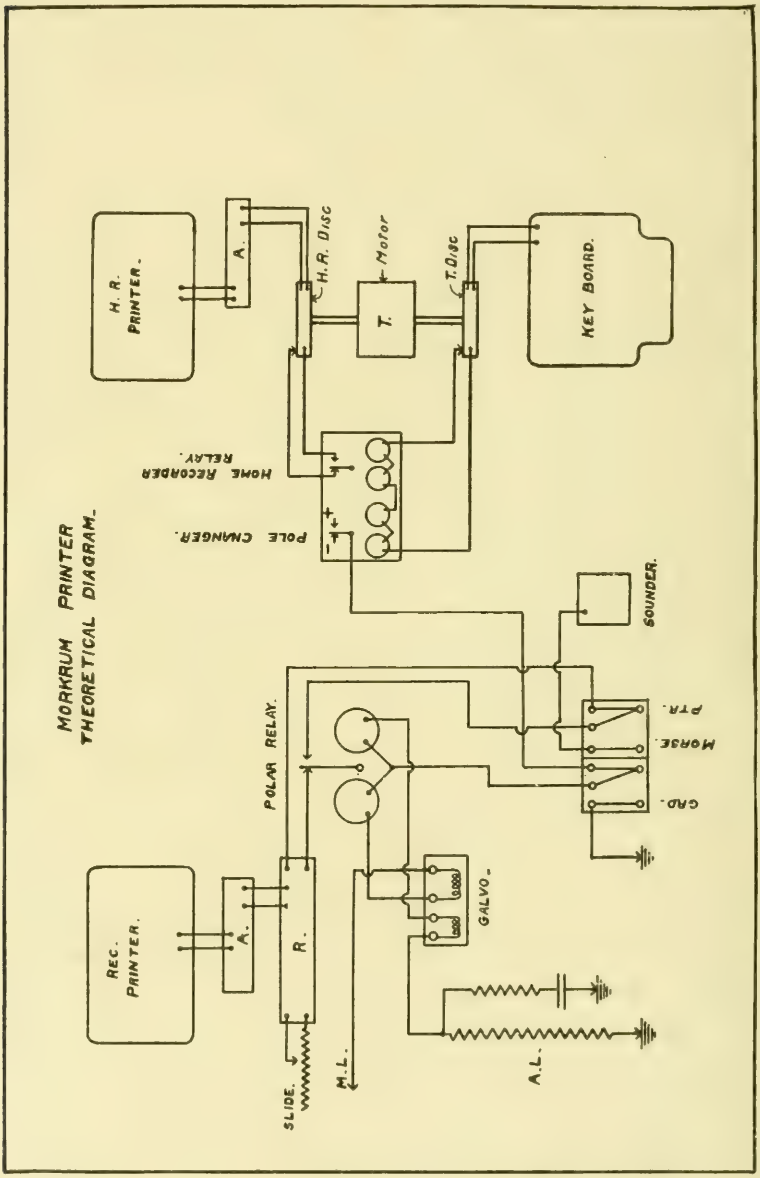


Fig. 33. Complete Wiring Diagram of Sending and Receiving Circuit of the Morkrum Telegraph
Courtesy of Morkrum Company

Receiving Apparatus. At the receiver are a relay in the main line, two banks of relays, and a printer with various circuits and magnets controlled by the selecting relays. The receiver operates at approximately the same speed as the transmitter but perfect synchronism is not necessary. The starting impulse coming over the line reverses the line relay contact and thus energizes the magnet of the first of a series of relays known as the receiver bank. The tongue of this first relay makes battery connection for the coil of the second relay, and in the same manner the other relays in the bank are successively operated. These relays are so wound and adjusted that their succession in operation corresponds in time with the unit time intervals of the transmission.

The tongue contacts of these relays make selective combinations in the printer to effect its various operations. The typewheel is carried on a hammer shaft and at the proper moment is forced against the paper by a magnet. A complete assembly of the transmitting and receiving outfit is shown in Fig. 34.

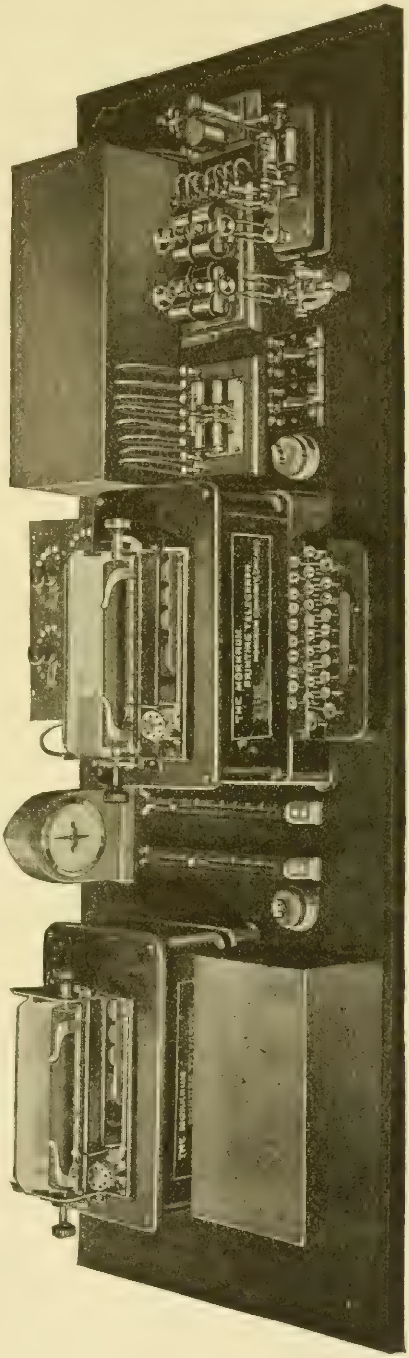


Fig. 34. Assembly of Transmitting and Receiving Outfit of Morkrum Telegraph
Courtesy of Morkrum Company

Automatic Transmission Printers

Buckingham Page Printer. The Buckingham Printer was invented by Charles L. Buckingham, of New York, assisted by E. Germann. A specially punched tape is used with a Wheatstone transmitter for automatic sending. A keyboard machine is used for preparing the tape.

The printer takes ordinary telegraph blanks which are loosely curved around a tubular carrier with their edges joined together. The paper revolves by a step-by-step movement, controlled by a printer escapement. By this means printing goes on continuously, for instead of returning a carriage to begin a new line the paper is moved the distance of a line space, without loss of time.

The electrical principles of this printer have been embodied in the typewriter printer next to be described, devised by J. C. Barclay, formerly General Manager of the Western Union Company.

The Buckingham Printer was used by the Western Union Company during about four years. It was duplexed between New York and Chicago, with Wheatstone repeaters at Buffalo, sending 200 messages an hour on a line having a resistance of 3 to 5.5 ohms. On one occasion 2429 words were transmitted in less than 24 minutes; on another, 6073 words were sent and received in 60 minutes and 13 seconds. An average speed of 100 words a minute has been maintained.

Buckingham-Barclay Typewriter Printer. The Barclay Printing Telegraph, the diagram for the mechanism and circuits of which are shown in Fig. 35, is an adaptation of the electrical principles of the Buckingham invention to working a typewriter instead of the special Buckingham printing mechanism. The keyboard tape puncher is used to prepare messages for Wheatstone transmission. As in the Buckingham, six currents of alternating polarity and varying duration are sent to print each letter, three negative marking and three positive spacing pulses. Of these six pulses one at least must be prolonged, corresponding to a dash in the dot and dash code. Five pulses serve to bring any letter to the printing point, while the sixth operates the print and feed magnets and other mechanism.

The line signals are received by a polarized relay the armature of which controls a printer relay which in turn actuates (a) a governing or separator relay which responds only to pulses of dash duration, not to shorter signals; (b) an escapement magnet which controls a step-by-step escapement wheel which turns half a tooth for each line impulse; and (c) a polarized unison or synchronizing magnet which responds only to prolonged spacing currents.

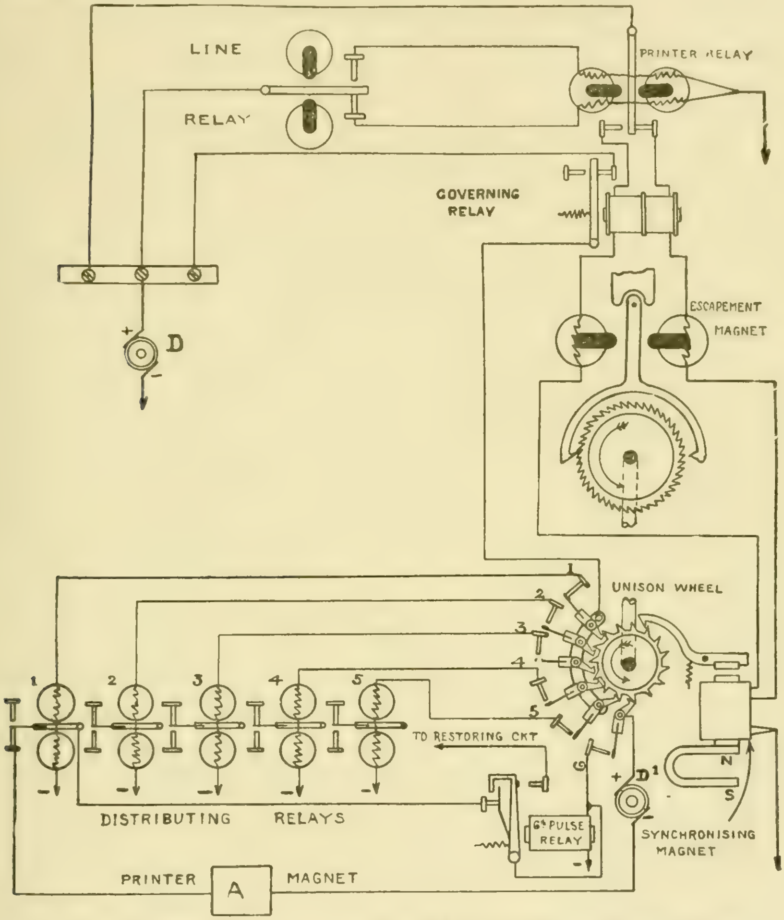


Fig. 35. Diagram of Mechanisms and Circuits of the Buckingham-Barclay Printer

The action of the unison magnet is to permit a unison wheel, which is also the current distributing wheel of the "sunflower", to turn step-by-step with the escapement wheel on the same shaft, so long as unison is maintained. The unison wheel has a number of teeth, the space of one tooth corresponding to three teeth on the escapement wheel; consequently the unison wheel turns step-by-step one tooth while the escapement wheel responds to six line pulses.

The synchronizing magnet is actuated only by a long spacing current which follows each letter. So long as the line pulses come regularly and operate the escapement wheel, the synchronizing magnet comes into action after each letter and withdraws a catch from between two teeth of the unison wheel; but if any line pulse is interrupted or lost, the magnet would fail to act and the unison wheel would be held until released by five short pulses of a succeeding letter which would restore the unison.

The teeth of the unison wheel, as it turns step-by-step, engage successively with six pivoted radial-spring contact arms to which circuits *1*, *2*, *3*, *4*, and *5* are electrically connected. These arms make contacts in numerical succession with the windings of correspondingly numbered selecting or distributing relays, but the circuit is not completed for any relay until the governing relay magnet is energized by a prolonged line pulse. If the first pulse is a prolonged one, the first relay will be energized; if the second is a long pulse, relay *2* will respond, and so on. For example, the letter A is signaled — . . ; the first arm circuit will thus be established and relay *1* will make contact for the printer magnet. The successive short pulses will cause the unison wheel to continue its step-by-step movement, but the contact at the separator relay being broken, no other relay will participate in forming this letter. If the letter K is signaled — — —, the arms and relays *1*, *3*, and *5* will be engaged in forming the necessary combination for printing that letter.

Thus five of the six impulses make up the combinations for all letters. The sixth pulse, always a prolonged one, follows through the sixth pivoted arm and the sixth pulse relay, whereby the printer magnet is brought into action.

The five distributing relays afford 32 different combinations whereby any one of 32 printing magnets may be selected as desired. In the Barclay apparatus, 28 letter magnets serve to actuate the printing mechanism of a certain form of typewriter, and four others affect the paper feed, shift, spacer, and carriage return.

This apparatus is doing good work on Western Union wires and its application is being extended.

Pollak-Virag Telegraph. This remarkable invention has been developed at Budapest by Anton Pollak and Joseph Virag. In its original form, 1899, it transmitted Morse signals from punched tape and recorded them photographically on a paper slip, not as dots and dashes but as vertical displacements of a horizontal line, an upward movement corresponding to a dash and a downward movement to a dot. A representation of such a record is shown in Fig. 36.

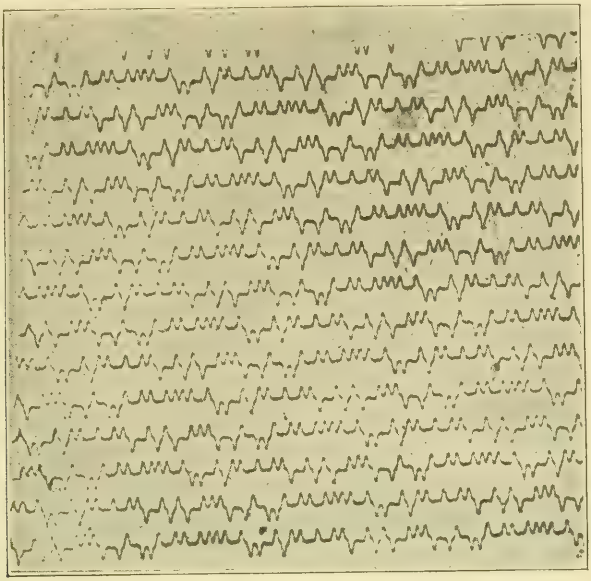


Fig. 36. Photographic Record of Pollak-Virag Morse Message

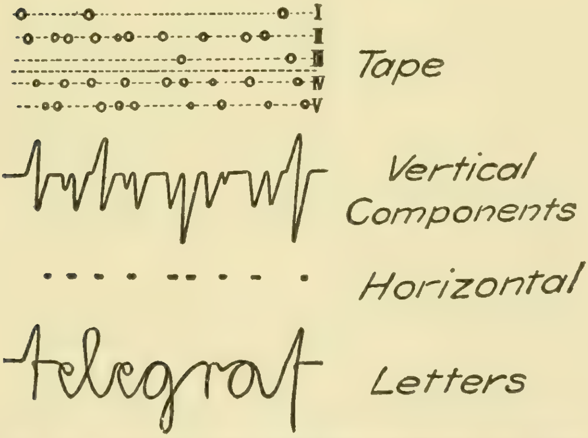


Fig. 37. Diagrams of Pollak-Virag Tape, Components, and Writing Characters

Sending Tape. The tape is punched with two rows of holes and passed through a transmitter in the usual way under two brushes which send positive and negative currents to line over two wires.

Receiver. The receiver is a telephone the diaphragm of which is connected by a rod with a small, very delicately suspended concave mirror. The vibrations of the diaphragm affect the mirror and its movements are recorded by reflecting the image of an incandescent filament on sensitized photographic paper wound upon a revolving drum. As line currents come, the light beam moves up or down according to the polarity of the successive pulses.

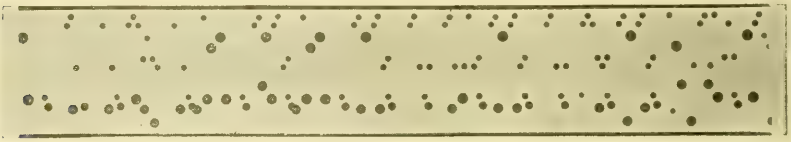


Fig. 38. Pollak-Virag Tape Used in Transmitting the Message Reproduced in Fig. 39.

This apparatus has made wonderful records in speed of Morse transmission, as attested by persons of note and experience.

Method of Action. In its latest form messages are recorded in writing script. It is a writing telegraph of remarkable character. To accomplish this result, the sending tape is punched with five rows of holes, and the holes are varied in size according to requirements of more or less current. The reflecting mirror is subjected to the joint action of two telephone receivers, one giving the vertical movements, the other the horizontal. Very ingeniously these are made to produce looped letters like the written *l*, for example. Fig. 37 shows how the tape is prepared for the

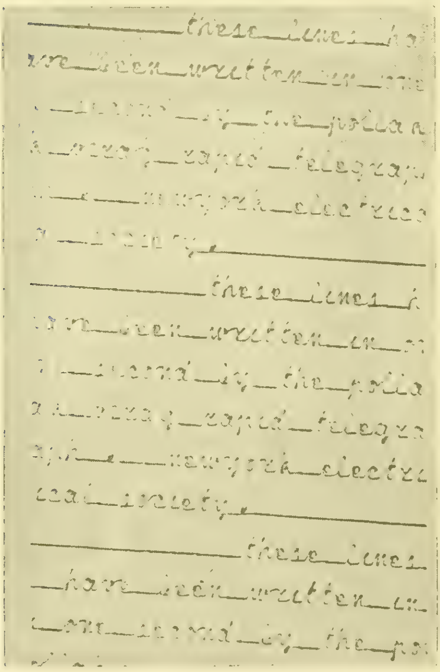


Fig. 39. Photograph of Message Sent by Pollak-Virag Telegraph System

writing transmission and indicates how the vertical and horizontal marking components are combined by the two telephone diaphragms to form letters.

The claim is made that it is possible to send over a long telegraph wire at a speed of 1000 words a minute and that the writing is good at that speed. The Morse apparatus operates at greater speed. Such almost incredible results excite admiration and wonder. It remains to be seen whether the inventors are destined to receive adequate reward for their ingenuity and efforts from the application of this brilliant conception to commercial use.

Fig. 38 is photographed from tape used in transmitting the message photographically reproduced in Fig. 39. This message was transmitted over a short local wire.

Automatic Tape-Punching Printers

Murray Automatic Printing Telegraph. The Murray Automatic Telegraph was devised by Donald Murray, who before he entered this field of invention was engaged in newspaper work in Australia. His original purpose was to punch tape that would mechanically operate a typesetting machine and thus increase the speed of composition. The first demonstration of his apparatus in this country was made at the Astor House, New York, in 1898, under the name "Automatic News System". His invention was taken up by the Postal Telegraph Company and for some time experimentally operated between New York and Chicago.

Sending Tape. The tape used in transmission is prepared by a keyboard puncher and passes through a Wheatstone transmitter the operation of which is somewhat modified since alternations of current are not regularly used. Uniformity in transmission, which is necessary for synchronous working at both ends of the line, is attained by vibrating reed control of the transmitting mechanism.

Transmission Current and Sending Method. The transmission current differs radically from any heretofore described, and is a very important part of the invention. Instead of alternations of current and dot, dash, and space impulses, each letter is the same in respect to length on the tape and duration of time, and is made up of makes and breaks in the current of different units in duration, all together equivalent to a duration of five units. As will be shown, the synchronizing, spacing, and punching are not done by the line current but by local battery currents established by the line relays of the receiver. Therefore, it is not necessary to send over the line combinations to effect these operations and the average number of pulses transmitted for letters is 1.25, the greatest number 3. Thus five units of time afford 32 combinations and these can be utilized in practice for 87 different characters. In the main line at the receiving end are a punching relay and a governing relay, with the synchronously vibrating reed of the receiver constantly interrupting local circuits through the tongues of the two relays. The vibration of this reed must be synchronous with the transmission currents and this condition is maintained by means of a vibrator magnet. This magnet is in a second local circuit which includes the tongue and back contact of the governing line relay. This whole arrangement insures synchronism and spacing of tape. When a line current actuates the punching relay, this relay operates the punching magnet. The circuit of this magnet being continuously interrupted and closed by the vibrating reed, which also controls the tape movement escapement, the number of holes punched in the tape will be determined by the duration of current through the punching line relay magnet—in other words, by the duration of the units of length of the line current.

The Murray invention is not properly a telegraphic printer since a printed message is not received directly from the wire, but a tape is punched, a reproduction of the original transmission tape, which may in turn be used either for a retransmission or to operate a typesetting or a typewriting machine automatically. The Murray system has been considerably used on long lines abroad and is apparently developing in a large way. The line operating speed is said to be as high as 100 words a minute while the printer can be operated with tape at about double that speed, although the usual speed is approximately the same as the transmission.

Creed Tape Puncher and Telegraph Printer. This is the invention of F. G. Creed, formerly of Nova Scotia, now of Glasgow, Scotland. The perforating receiver is an apparatus for reproducing Wheatstone tape at a distance, thus avoiding hand retransmission. The punches are operated by compressed air. The telegraph printer is a later development and, like the Murray, is a printer mechanically operated by the punched tape of the receiving apparatus.

The Creed inventions have been favorably received abroad and seem to be rapidly coming into use. As the regular Wheatstone tape with Morse code is used, this factor makes the apparatus immediately applicable.

AUTOMATIC AND HIGH-SPEED TELEGRAPHS

Printing and other telegraph devices using punched tape for transmission instead of manual work are properly automatic machines, but distinctively high-speed telegraphing utilizes in far greater degree the possibilities of rapid automatic transmission and recording. While mechanical printing and punching apparatus necessarily sets a relatively low limit to practicable speed, which, even by multiplex working, falls far short of the electrical limitations of wire transmission, modern high-speed automatic methods permit the full utilization of the message carrying capacity of a wire. Mechanical movements of any kind directly effected by line current not only materially limit operating speed, they also introduce various complications, both physical and electrical. High-speed automatic methods, on the other hand, are in the highest degree simple; no mechanical work is done by the line current and the mechanical equipment for moving tape is inexpensive.

Wheatstone Automatic Telegraph. Intermediate between automatic printers, tape punchers, etc., and high-speed methods with chemical recording, is the Wheatstone Automatic, which, although limited in speed by electromagnetic and mechanical restrictions, is nevertheless a very rapid and highly developed telegraphic apparatus. It was patented in England in 1858. Perforated tape is used in transmission and the receiver is an ink recorder; the marking is controlled by a very sensitive polarized relay. The tape is usually prepared by a three-key hand puncher although keyboard machines are coming into use. The punched tape has three rows of holes, as shown in Fig. 40, the middle row of small holes serving only to control the regular movement of the tape in the transmitter by engaging with the sprocket wheel teeth.

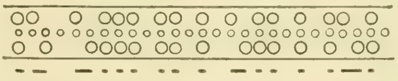
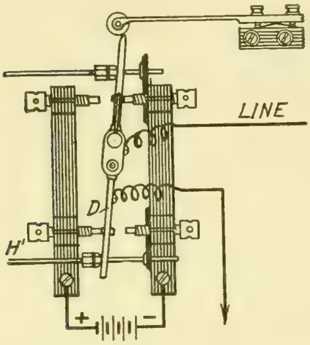


Fig. 40. Wheatstone Automatic Telegraph Tape

Operation of Transmitter. Both transmitter and receiver are driven by clockwork. The operation of the transmitter is indicated in Fig. 41. The prepared tape passes above two upright rods *LL′*, which are pressed upwards by springs *s*. As the rocking beam moves, the levers *HH′* operate the pole changer disk *D*, the movement of which is limited by the stops *tt′*. When the rod *L′* passes through a hole in the tape, the pole changer sends positive current to line from the battery through contact lever *CL′* and pin *2* on the insulated right-hand side of the pole changer disk. This current will continue until the other upright rod *L* passes through a hole in the other row of the tape, when the pole changer contacts will be changed and a reversal of current to line ensues. If the passing of the holes corresponds with the successive movements of the rocking beam, then regular short alternations of current will be sent to line as dot signals. When the holes are spaced as for dash signals, then the rod *L* on rising meets with unbroken tape instead of a hole and its upward movement is arrested. The rocking beam continues its regular motion, but the pole changer is not reversed and the contact at *2* continues. Rod *L′* in turn likewise meets with the tape and ceases to rise, but when *L* comes up again it finds a hole and reverses the contact at *2*. The upper figure shows a modified form of the pole changing apparatus.



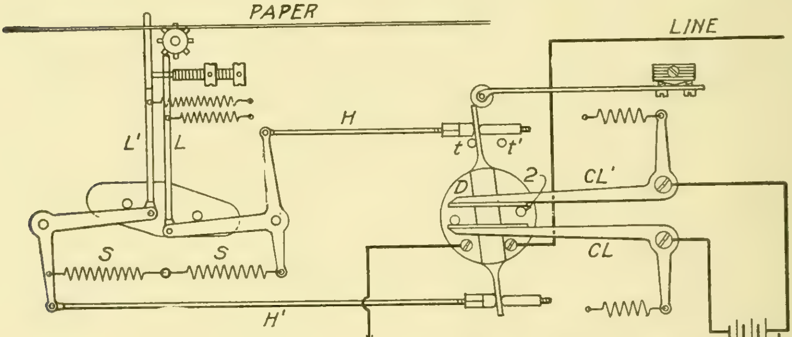
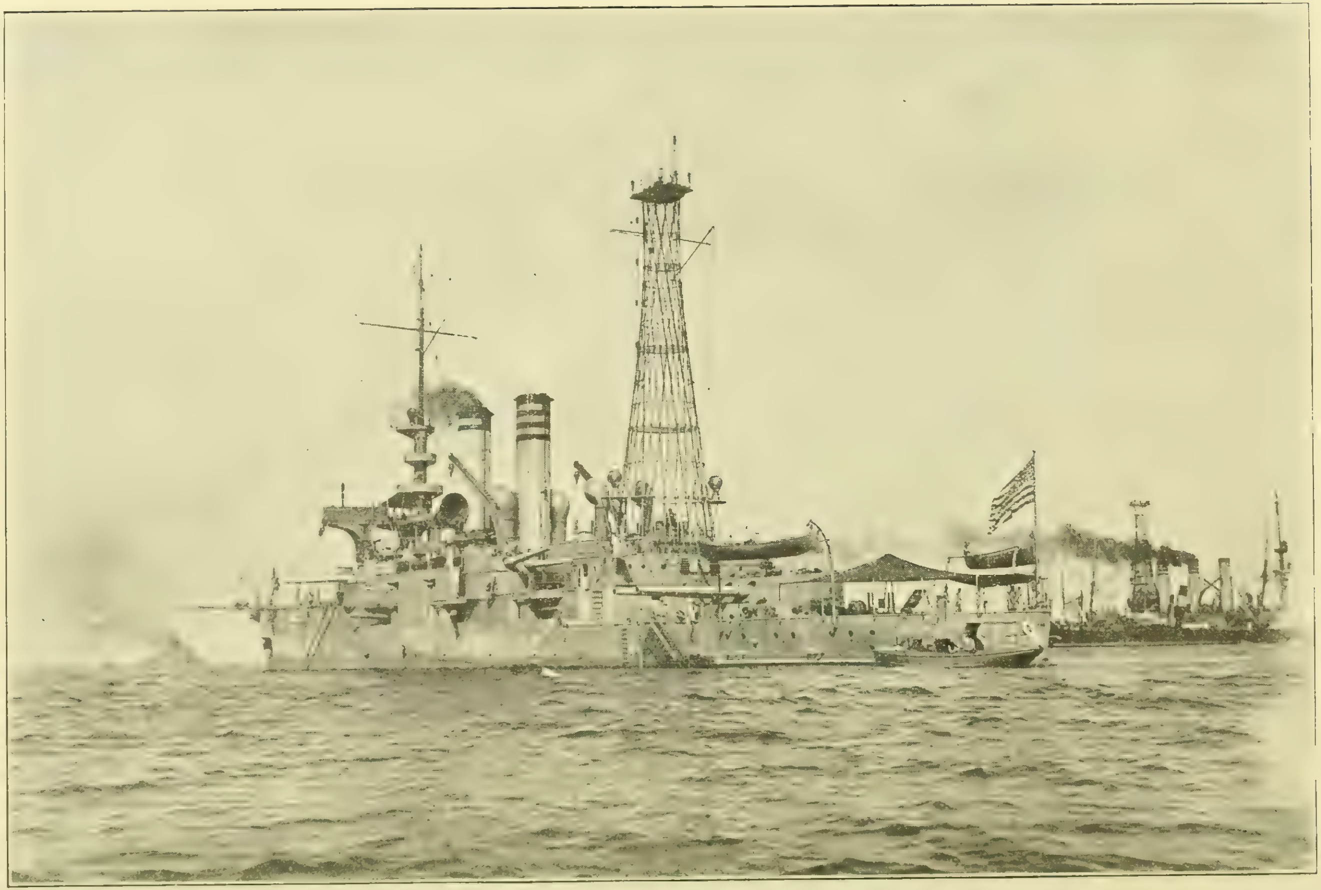


Fig. 41. Diagram Showing Construction and Operation of Wheatstone Transmitter

Thus long and short marking currents of one polarity are trans-



BATTLESHIP SUPPLIED WITH WIRELESS TELEGRAPH EQUIPMENT

The New- and Old-Style Masts or Aërials are shown in Contrast—the New at the Right, and the Old at the Left.

mitted and recorded as dashes and dots at the receiver, with alternations of opposite polarity which are utilized for spacing.

Operation of Receiver. At the receiver, marking is done by a very sensitive polarized relay which brings a small inked wheel into contact with the moving tape for each marking current received and withdraws it for spacing currents.

Instead of the ink recorder apparatus for reproducing, the punched tape is coming into use. Such tape can be used for retransmission of messages, which heretofore has required first transcription and then repunching. The reproduced tape may also be passed through a transmitter at slow speed and transcribed from a sounder.

HIGH-SPEED METHODS

The principle of high-speed telegraphing is the same today as it was at the beginning. By means of a moving tape variously punched with one or two rows of holes, Fig. 42, contacts are made through the holes by a conductor, a spring, or a brush, connecting the line with an electrically charged surface, Fig. 43. These contacts may follow each other with a rapidity depending only upon the speed of mechanical operation, which is far in excess of any possible electrical actuation of a mechanical receiver. At the receiver the currents pass by means of a small metal recording wire through a chemically

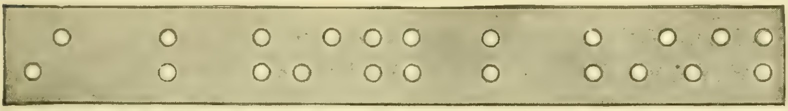


Fig. 42. Section of Delany Transmitter Tape, Characteristic of Most High-Speed Telegraph Systems

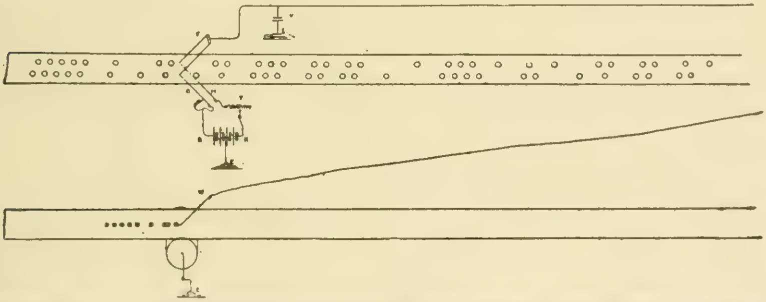


Fig. 43. Diagram Showing Sending and Receiving Mechanism for Delany Telegraph Circuits

prepared running tape and thence to ground. The chemically prepared tape usually contains a preparation of potassium ferricyanide and the wire is of iron. A positive current effects electrolytic decomposition and makes a blue mark, the length of which depends upon the duration of the current. A negative current makes no mark. Thus dots and dashes can be recorded as rapidly as the current can affect the paper, Fig. 44, and this speed is almost incredible. The Delany apparatus has recorded legible signals at a speed of 8000 words a minute. The practicable speed of commercial operation is therefore limited only by the electrical conditions of wire transmission, which is largely governed by distance. The electrical conditions are especially noticeable in their effect upon sharp definition of signals sent at high speed. Therefore, simple as the high-speed method is in both theory and practice, only recently have means been devised that make it the most perfect and reliable method of telegraphic communication, commercially practicable and convenient for the handling of large business.

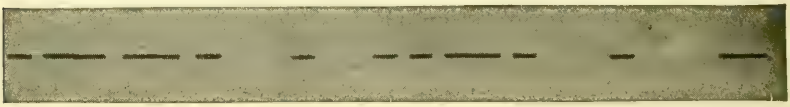


Fig. 44. Delany Receiver Tape Showing Morse Record Produced by Chemical Means

Dyer Chemical Telegraph. It is generally supposed that the Bain was the first chemical recording telegraph; but it appears, from almost forgotten records, that the first chemical telegraph antedated the application of the galvanic battery and the discovery of the electromagnet. The Hon. Harrison Dyer constructed a telegraph line on Long Island, in 1827. He strung wires on poles with glass insulators and used frictional electricity, with ground return. Messages were received on paper prepared with litmus, apparently with the addition of some chemical compound which developed a red mark when acted upon by a spark from the wire. The paper was moved by hand and the difference in time between sparks indicated different letters. The line was used for some time and it was proposed to establish business between New York and Philadelphia, but adverse conditions arose and Dyer was forced into seclusion.

Bain Automatic Telegraph. In the early days of the telegraph Alexander Bain, of Edinburgh, came to this country and, in 1848, introduced his automatic telegraph with chemical recording, which was patented in England, in 1846. The tape was punched with two rows of square holes grouped to represent letters in the adopted telegraphing code, as shown in the upper ribbon of Fig. 45.

The tape was run over a metal cylinder connected with a battery. Two springs made electrical contact through the holes as the tape was running. Two wires connected the springs with corresponding iron recording needles resting upon a strip of chemically prepared paper at the receiver. Positive currents were thus sent over the wires and made a record such as is shown in the lower ribbon of Fig. 45.

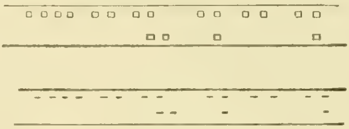


Fig. 45. Bain Automatic Telegraph Tape Showing Sending and Receiving Record

Bain soon discarded this two-wire method and adopted a tape with long and short perforations in one line, which permitted the transmission of dashes and dots over one wire. He had no good method for preparing the tape and therefore soon adopted a key for signaling and used chemical recording.

This method was used on lines between New York, Washington, and Buffalo in 1849-1850, and at one time 2000 miles of wire were in use. The last circuit operated was out of Springfield, Massachusetts, about 1859.

Little Automatic Telegraph. This modification of the Bain invention was patented by George Little, of New Jersey, who devised an electromagnetic tape puncher. A key puncher was also used which prepared tape with holes in two rows, the upper row large, the lower small and uniform, as shown in Fig. 46. The large holes bridged over the small holes to make dashes. A number of improvements were applied to cut off the "trailing" of the marks due to discharge of the line after signals. A magnetic shunt or leak to ground was introduced at the sending station, also a shunt and adjustable resistance—afterwards an electromagnet—around the receiver.

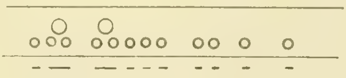


Fig. 46. Section of Little Automatic Telegraph Tape

The Little apparatus came into extensive use and operated very successfully up to 1877, when it fell under control of the Western Union Company and the Morse key took its place.

Foote and Randall Automatic Telegraph. In this apparatus the double current method was applied, the tape being punched with holes in two rows, as indicated in Fig. 47. The tape passes over two metal drums placed side by side, insulated from each other and connected with opposite poles of the two batteries. The circuit is shown in the illustration. Contact is made with the drums by two brushes in the usual way, whereby positive and negative currents are sent to line as the holes pass through the brushes. It will be seen from the diagram that successive marks, whether dots or dashes, are punched in alternate lines on the tape, one hole for a dot, two close together on the same line for a dash. The receiver has two marking points which receive current from opposite sides of the tape. Since only positive current makes a mark, all marks by one needle will be made by the current over the wire, those by the other point by current from the other battery through the earth. Dots are made by single short currents, dashes by two short currents in such rapid succession that on the chemical tape the discharge of the line fills the gap between them.

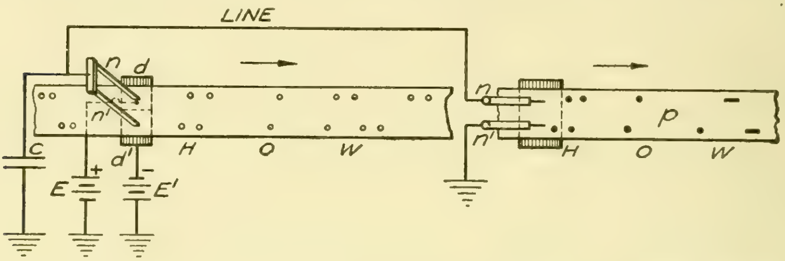


Fig. 47. Diagram of Sending and Receiving Mechanism of Foote and Randall Telegraph

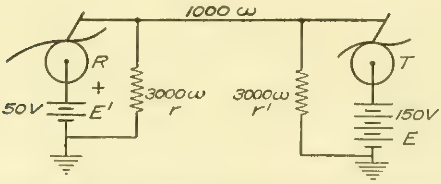


Fig. 48. Arrangement of Circuits for the Leggo Automatic Telegraph System

This method was used by the American Rapid Telegraph Company about 1880 to 1884. On the New York and Boston line 1000 words a minute could be sent and received, but the usual working speed was 500 words.

Leggo Automatic Telegraph. The feature characterizing this telegraph was a method of preparing messages for transmission by means of an insulating ink deposited in a spiral of dots and dashes on a revolving metal cylinder. Otherwise it is the Bain telegraph with means for cutting down the trailing. The general arrangement is shown in Fig. 48.

This telegraph was used by the Postal Telegraph Company and actually worked between New York and Chicago at a speed of 1200 words a minute.

Anderson Automatic Telegraph. This invention presents some novel features. The tape is prepared by a special punching machine. A single row of holes is used but these are of two sizes, as shown in Fig. 49. The tape passes over a conducting cylinder in the usual way, but the unique feature is that the holes do not represent the signals recorded on the receiver tape. The main battery is directly and continuously connected with the line. As the conducting brush falls into the holes it short-circuits the line, thereby causing a sudden drop in potential on the line. The battery current goes to line only when the brush rests on the paper between the holes, therefore the distance between the holes determines the signals for dots and dashes.

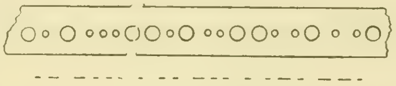


Fig. 49. Section of Anderson Automatic Telegraph Tape

Delany Automatic Telegraph. The Delany telegraph has passed through so many stages of electric and mechanical improvement that the name properly applies to several forms of apparatus, each marking a distinct advance in the art. The inventor has applied his long

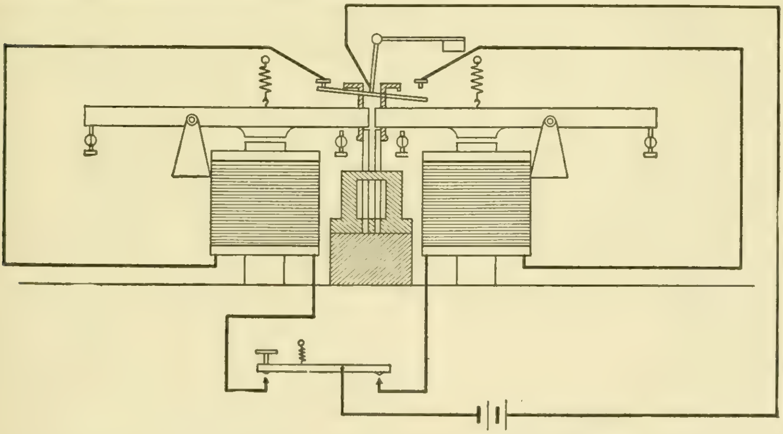


Fig. 50. Morse Key Tape Puncher for Delany Telegraph

telegraph experience and exceptional ability not solely to perfecting apparatus and methods for line operating, but also to other details of importance in relation to these, which, however, cannot be here described.

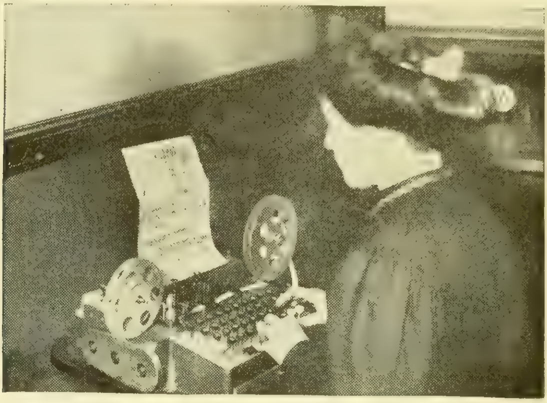


Fig. 51. Delany Keyboard Tape Puncher

The earlier methods of automatic working were defective in several respects and, although some of them afforded good service, it may well be questioned whether they would prove equally satisfactory in operation in these days when line disturbances are very much greater.

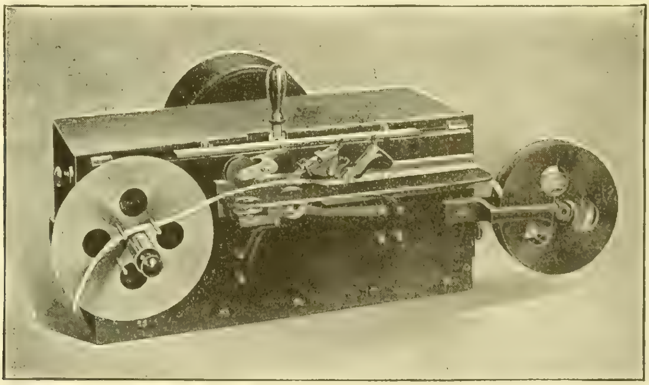


Fig. 52. Delany Transmitter

One most important desideratum in fast wire signaling is to have all impulses of equal duration. This was achieved by Delany for Morse working, in a method described before the Franklin Institute in 1895. The next forward step advanced automatic telegraphy to such a point of perfection that it permits virtually the full utilization of the theoretical efficiency of wires as regards speed of signaling.

The problem was to record Morse dots and dashes in a single line, using impulses of equal duration. This was accomplished by reversal of current after every marking (positive) impulse. When a reversal follows quickly, the marking current is suddenly neutralized and a dot is recorded. By slightly delaying the reversal the discharge of the line lengthens the mark on the running tape until the reversal cuts it off.

By this method the static charge of the line, which hitherto has proved seriously detrimental to speed, not alone in high-speed operating but in other methods as well, is utilized as an important adjunct for operation at speeds approaching the theoretical limit.

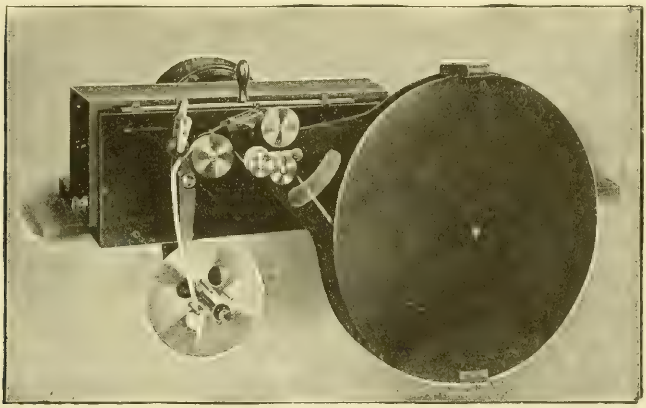


Fig. 53. Delany Receiver

The tape is perforated in various ways, either by a Morse key, as shown in Fig. 50, or by a keyboard puncher, Fig. 51, or by a three-key puncher similar to the Wheatstone. The transmitter and receiver are shown in Figs. 52 and 53.

SUBMARINE TELEGRAPHY

Submarine telegraphy performs a very important function in the world today. Its influence on social, commercial, and political activities in all civilized nations, although perhaps but little realized by the average individual, is really very great. Submarine cables are generally established to meet political or commercial rather than social demands. In the case of the Atlantic cable of 1868, both commercial and political needs were factors which brought financial assistance to the undertaking. The Transpacific cable, completed in 1903, was due mainly to commercial influences, while the British cable from Vancouver, British Columbia, to Australia was laid chiefly for political reasons.

Problems of Operation. *Dangers of High Potentials.* The first Atlantic cable was probably ruined by high potentials alternating from an induction coil which were applied in the hope that the speed of signaling would thereby be increased. Professor William Thomson, who later became Lord Kelvin, pointed out the fallacy of such a plan, and it was experimentally shown that signals could be transmitted with nearly the usual speed by means of current from a tiny battery made of a single percussion cap containing a drop of acid and a zinc rod.

In modern cable practice low potentials—from forty to seventy volts—are employed, and only very small charges are sent into the cable, it being connected to the battery through condensers.

Electrostatic Capacity. A submarine cable has by virtue of its structure and dimensions a large electrostatic capacity between its conductor and the sheath or ground. When a difference of potential is applied between the conductors and sheath, it acts like a large condenser and therefore requires a considerable quantity of electricity to raise its potential appreciably. This is one of the reasons why it is more practicable to use low rather than high voltages, while considerations of liability of accidental puncture afford another important reason for the use of low voltage and correspondingly more sensitive recording instruments.

Series-connected terminal condensers placed at each end of a submarine cable serve two purposes: (1) they eliminate earth currents from the cable, thereby giving more regularity to the record and making it easier to read the tape; and (2) they tend to make the record signals more distinct, sharp, or separate.

Duplex Operation of Submarine Cables. Duplex operation of land telegraph lines was introduced commercially in 1858, and the same year William Thomson patented a duplex method of operating submarine cable; this, however, was not immediately applied to commercial operation. The Stearns duplex method, although successful on land lines, was not practicable for cable work because with resistance coils alone it was impossible to balance the local circuit with the cable circuit.

In 1862, Varley patented an artificial cable having both resistance and capacity. With the Varley device a better balance was obtainable, but it was not until Muirhead produced an artificial line having resistance and capacity uniformly distributed that the problem was so satisfactorily solved as to make duplex cable operation commercially successful. At the present time practically all submarine cables are operated duplex and at a signaling speed for each side of the duplex of about eighty per cent of the speed for single circuit operation.

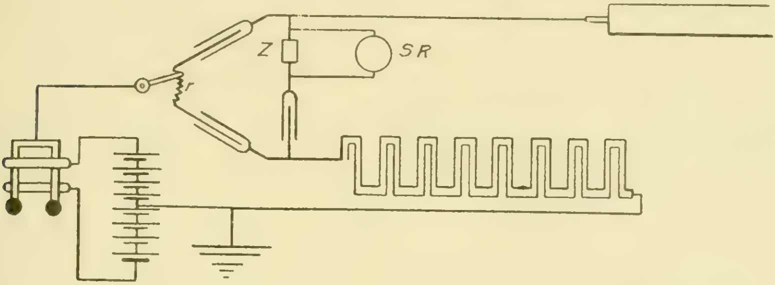


Fig. 54. Wiring Diagram for Duplex Operation of Submarine Cables

Fig. 54 is a simplified circuit diagram, showing a method of connecting the equipment for duplex operation of submarine cables.

INSTRUMENT EQUIPMENT

Cable Transmitters. Cable messages are sent by means of hand-operated keys and by automatic machine transmitters. Hand-operated keys, Fig. 55, are used for rush messages where the additional time required to prepare the perforated tape necessary for automatic transmission would cause serious delay. As an illustration of the speed sometimes demanded, it is expected that an order from a New York Stock Exchange broker to his correspondent in the London Stock Exchange will be delivered in two or three minutes from the time it is written. In a record case it is

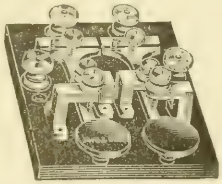


Fig. 55. Hand Cable Key

claimed that such an order has been transmitted, the stock order filled, and the confirmation of the purchase delivered to the buyer within three minutes time. Other cases in which there is no time to prepare tape are frequent, the most common being a request from the distant operator to have part of a message retransmitted if it is not understood, and to check or correct errors.

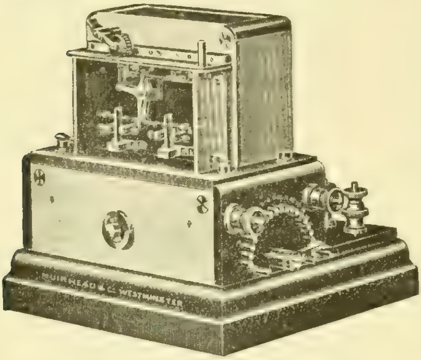


Fig. 56. Standard Type of Automatic Cable Transmitter

Automatic transmitters, such as illustrated in Fig. 56, and described more in detail under Automatic Telegraphs, are used for regular cable messages because of the greater uniformity and regularity of the transmitted impulses and the much better records produced thereby. The characteristic differences in records made by machine transmission and by key transmission may be seen by referring to page 77 and Fig. 59.

Many automatic machines have been devised for perforating transmitter tape but the old mallet type hand-operated punch, shown in Fig. 57, is used in this country more than any other type. On circuits over which the American Morse code is used, there is no simple means of operating automatic punches to punch tape for the Continental Morse code which is used over all submarine cables.

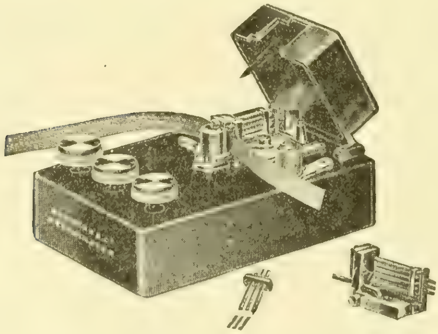


Fig. 57. Mallet Hand-Operated Tape Punch

Cable Recorders. The first receiving apparatus used commercially on submarine cables was not, strictly speaking, a recorder, for it left no permanent record. It was essentially a mirror galvanometer. Signals were read by watching the movement of a spot of light which was deflected by a mirror attached to the galvanometer needle.

Spark Recorder. The first real recorder, known as the "spark recorder", may be regarded as the forerunner of the siphon recorder. The spark recorder consisted of a sensitive galvanometer with a metallic pointer arranged to freely swing across and slightly above a uniformly moving paper tape. By means of an induction coil, sparks were rapidly discharged from the free end of the pointer through the moving paper tape to a metal plate. Thus a series of minute punctures recorded the movement of the pointer, making a permanent record.

Siphon Recorder. The siphon recorder, a modern form of which is shown in Fig. 58, is a very successful type and is, with various modifications, used on practically all submarine cables. Like the spark recorder, it makes a record on a paper tape, but the recording line instead of being a series of punctures is a series of ink spots. There had been many attempts to make an ink-writing recorder, but the cohesion of particles of ink on the paper with particles on the pen was so great that the small force acting to move the pen could not overcome the cohesion and hence the devices did not work. In the original Thomson siphon recorder the point of the

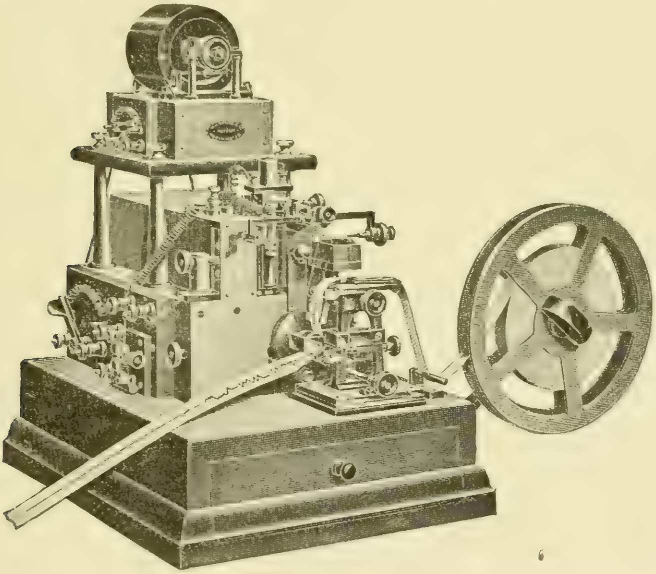


Fig. 58. Standard Type of Siphon Recorder

siphon pen did not touch the paper but, owing to electrostatic attraction, minute particles of ink on the siphon tube were projected to the surface of the paper ribbon in rapid succession, thus tracing a line of ink spots which recorded the movements of the coil and pen. By giving careful attention to the design of the various parts, Thomson very greatly increased the sensitiveness of this recorder. One of the important points which he recognized was the necessity of keeping the movement of the coil small so that the inertia effect would be low. Accordingly, he devised a multiplying device to magnify the movements of the coil so that the record would be legible.

Cuttriss Recorder. A simple and very reliable electromagnetic vibrator was substituted by a Mr. Cuttriss for the more cumbersome and uncertain electrostatic device, by means of which the ink is put on the tape at rapidly recurring intervals of time. The vibrator is so arranged that the end of the siphon is given a rapidly alternating motion normal to the plane of the paper tape. It is so adjusted as to just touch the ink to the paper and then pull the tube away so it will be free to swing in a plane parallel to the tape.

Most of the recent changes in the design of recorders are matters of detail. The size of magnets has been greatly reduced, and some makers are placing a special winding around the permanent magnets to restore them to normal strength after they have been weakened from any accidental cause.

CABLE CODES AND RECORDS

Continental Code. It was stated in connection with simple Morse circuits that the Continental code is the one used on submarine cables. This code differs from the American Morse code, as may be seen from Table I, page 81, in not having spaces between the dot and dash elements which represent each letter. This code was designed for operation with the needle telegraphs of Cooke and Wheatstone, for which the American Morse with its spaced signals was not well suited.

Recording Methods. *Difficulty in Using Spaced Signals.* Owing to the high electrostatic capacity of a submarine cable, brief current impulses established at the transmitter to represent the dot and dash signals become at the receiver end long-continued current discharges. If the current impulses from the transmitter are all of the same polarity and follow in rapid succession, the current discharges at the receiver end of the cable overlap each other, producing an almost uniform current, variations in which would be difficult to detect. It is, therefore, apparent that spaced signals, as in the American Morse code, would be particularly confusing. For example, the letters C ●● ● and F ●▬● would give practically the same result at the receiver. For this reason, the Continental code which has no spaced signals has been adopted on all submarine cables.

Positive and Negative Currents Give Dots and Dashes. Since both dot and dash impulses give long-continued current discharges not readily distinguished at the recorder, dot signals are sent by current impulses of one polarity and dash signals by impulses of the opposite polarity. One of the keys shown in Fig. 55 is used for sending dots, the other for dashes. Cable recorders do not make dots and dashes as did the Morse recorders formerly used on land lines, but instead a continuous wavy line formed by separate spots of ink is traced on the tape, as shown in Fig. 59. In this record, dot signals are represented by an elevation and dashes by a depression in the serpentine record. The upper tape is a record of the alphabet sent by means of an automatic machine transmitter over a cable at a rate of 160 letters per minute. The lower record is part of a message sent by a manually-operated key at a lower speed over a cable from Havana, Cuba, to New York. These two samples show clearly the characteristic differences between manual and automatic transmission. It should be noted that the record of the message automatically transmitted is much more uniform and would be read with less liability of error than the other. A comparison of the record of the

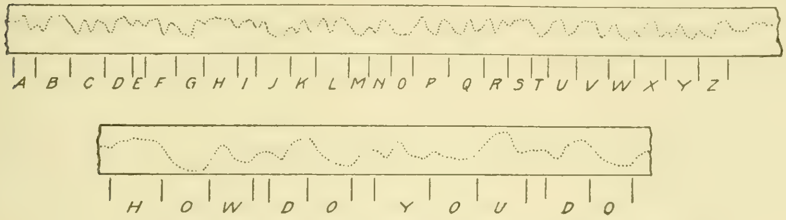


Fig. 59. Examples of Automatically- and Manually- Transmitted Cable Messages

letter H on each tape is particularly interesting as showing that the number of dots must often be estimated by the relative duration of impulses.

METHODS FOR INCREASING SPEED

The problem of the cable engineer is to get not only good clear signals, but also to send as many messages as practicable in a given time. As in the case of land-line telegraphy, two methods are available for increasing the number of messages handled per unit of time: (1) sending several messages simultaneously, and (2) sending one at a time but at high speed. Up to the present time it has not been feasible to transmit simultaneously more than one message in each direction over a submarine cable, the quadruplex and multiplex methods used on land being entirely inadequate.

Theoretical Considerations. A great amount of time and thought has been expended in trying to increase the speed of transmission of signals through submarine cables and at the same time retain clear and reliable records. It has been theoretically demonstrated that the speed of transmission of impulses through a cable decreases inversely as the product of its capacity and resistance. Practice has verified this statement and results show that on cables operated as single Morse circuits and using the Continental code the number of letters per minute equals 600 divided by the product of the resistance R in ohms and the capacity K in farads. Expressed in the usual form we have

$$\text{Letters per minute} = \frac{600}{KR}$$

Since the capacity and the resistance both vary as the length of the cable, the speed varies inversely as the square of the cable length. It would on this account be desirable to use a number of short lengths of cable and repeat the messages from one to the other. This is generally done where practicable, but it is found that repeating a message manually introduces additional chances of error which require time for verifying results and correcting errors. On this account a satisfactory cable relay is of very great importance. There are now in general use two very reliable cable relays, namely, the Brown drum relay and the Heurtly relay.

Brown Drum Cable Relay. One of the chief difficulties in the operation of the relay on a cable is due to the fact that the available pressure on the contact point is too small to produce a reliable circuit connection. This difficulty was overcome by S. J. Brown, who, in 1899, constructed a relay with a sliding brush contact held continually under pressure. The friction which would ordinarily result from the pressure is avoided in a very interesting manner. The brush bears on a rapidly revolving cylinder carrying two contact rings separated by an insulating section. In neutral position the brush rests on this insulating section technically termed "No man's land" but when current from the cable passes through the relay coil, it pulls the brush to one side or the other of the insulating ring, depending on the direction of the cable current. The brush thus makes contact with one of the contact rings and sends positive or negative current to line, as determined by the signals received. The high speed rotation of the contact cylinder is for the purpose of reducing as far as possible friction which tends to hold the brush from swinging.

Interpolator. The interpolator is used in connection with the Brown relay to automatically separate a long continued discharge, due to a series of dots, into the original component dots to give the correct retransmission. It consists of two mechanically-operated cams so arranged and timed as to cause the transmitter to send as many impulses of the required polarity as would correspond to the aggregate time represented by the long current impulse received from the cable.

Heurtly Relay. This very ingenious and successful relay makes use of an auxiliary Wheatstone bridge, across which is connected the transmitting device to be used.

The ratio arms of the auxiliary bridge consist of two minute platinum wires, each arranged near a very narrow slot from which issues a blast of cool air. The fine Wollaston platinum wires are normally kept hot by the current in the bridge arms.

The signaling current from the cable operates a sensitive galvanometer coil attached to the platinum wires, a very slight movement of which brings one or the other wire into the cool air blast, changes its temperature and, therefore, its resistance, and unbalances the bridge, thus operating the transmitter.

Magnetic Shunt. The so-called "magnetic shunt" is in reality an adjustable choke coil of low resistance and high inductance. When this inductive coil is shunted across the coil of a recorder, a portion of the total current passes through the recorder coil and the balance passes through the shunt. The characteristic feature of this device lies in the fact that at the beginning of a current impulse nearly all of the current passes through the recorder coil but, as time passes, an increasing proportion passes through the shunt. The effect of this is to cause the recorder coil to respond more promptly to the feeble signal impulses from the cable. In practice this device has been the cause of an increase in speed of about twelve per cent.

Magnetic Bridge. The so-called magnetic bridge is an adaptation of the magnetic shunt for use as a bridge for duplex cable operation. The inductive shunt is arranged in three parts, two of fixed magnitude and an adjustable middle section for balancing. The operation is the same as for the magnetic shunt. The practical result from the use of the magnetic bridge is an increase in the total number of signals per minute due to both a higher rate of transmission and to the simultaneous transmission of two messages.

Experimental Developments. Among the new devices for cable operation which are now being tried out are cable printers, new forms of cable relays, and a new system of cable operation.

Cable Printers. Some time before 1850, John Brett proposed the building of submarine cables and operating a printer of his design, but up to very recent times printing telegraphs have not been satisfactory for cable operation. Quite recently one of the large telegraph companies has put a printing telegraph into service on one of the cables connecting New York City with the terminal station of a transatlantic cable. The record is printed on tape, which is cut into suitable strips and pasted on a sheet for delivery.

Gott Method of Cable Operation. In connection with the subject of cable codes and records, mention was made of the advantage gained by making use of current impulses of one polarity for dot signals and the opposite polarity for dash signals. John Gott has recently patented a system in which each successive impulse is of opposite polarity from the one preceding, and thereby he secures the greatest possible benefit from the curbing effect of the reversed impulses. In this system the reversal of polarity is automatically

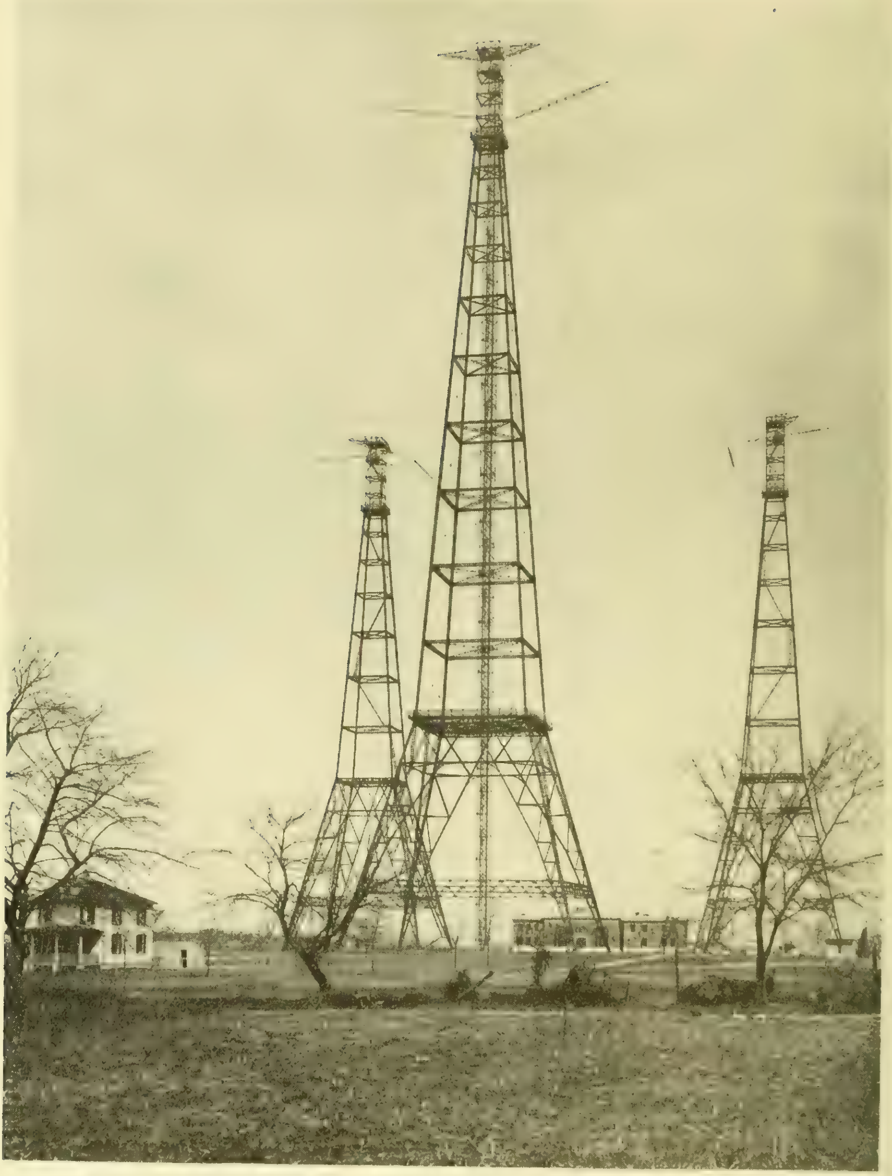
TABLE I

Telegraph Codes

Symbol	American Morse	Continental
A	• –	• –
B	– • • •	– • • •
C	• • •	– • – •
D	– • •	– • •
E	•	•
F	• – •	• • – •
G	– – •	– – •
H	• • • •	• • • •
I	• •	• •
J	– • – •	• – – –
K	– • –	– • –
L	—	• – • •
M	– –	– –
N	– •	– •
O	• •	– – –
P	• • • • •	• – – •
Q	• • – •	– – • –
R	• • •	• – •
S	• • •	• • •
T	–	–
U	• • –	• • –
V	• • • –	• • • –
W	• – –	• – –
X	• – • •	– • • –
Y	• • • •	– • – –
Z	• • • •	– – • •
1	• – – •	• – – – –
2	• • – • •	• • – – –
3	• • • – •	• • • – –
4	• • • • –	• • • • –
5	– – –	• • • • •
6	• • • • • •	– • • • •
7	– – • •	– – • • •
8	– • • •	– – – • •
9	– • • –	– – – – •
0	——	– – – – –
.	• • – – • •	• • • • • •
?	– • • – •	• • – – • •

made by a polarized relay through the winding of which the cable is connected to earth after each signal. The polarity of the cable discharge depends upon the polarity of the preceding signal and it is made to throw the armature of the polarized relay, thus reversing the battery from which the next impulse is sent.

The result of using alternate polarity for successive impulses is a great improvement in distinctness of signals, due to the curbing effect of the reversed impulses. In this system, dots and dashes are distinguished by the time interval between reversals of polarity and a very simple change in connecting the relay contacts enables a Morse sounder or ink-writing Morse recorder to be used. By this method a message has been sent, without manual repeating, from London, England, to San Francisco, California, using the Morse code and sounder. The practical value of the system is not yet determined.



UNITED STATES WIRELESS STATION AT RADIO, VIRGINIA

One of the largest and best equipped wireless stations in the world, having direct communication within a radius of over 3000 miles. The tallest tower is 600 feet high and the other two, 450 feet each. Towers are charged with 200,000 volts.

Photograph by G. V. Buck, Underwood & Underwood, New York.

WIRELESS TELEGRAPHY

INTRODUCTION

As a first step into the subject of wireless telegraphy it may be well to consider the meaning of the term. Wire telegraphy is characterized by the employment of extended metallic lines or conductors over which it is possible to transmit intelligence electrically by means of an arbitrary code of signals. Wireless telegraphy is characterized by the absence of such lines in the accomplishment of the same end. Many have confounded wireless telegraphy with the system invented by Marconi; but the latter is only one form out of many: the term was used to describe other systems years before Marconi's spectacular success added it to the popular vocabulary. As a matter of fact any system of telegraphy which successfully substitutes some other medium for the connecting wires, may properly be called "wireless." The systems of wireless telegraphy so far proposed may be classified as follows: Conduction Systems; Induction Systems; and Radiation Systems.

The history of the subject follows very closely the above sequence in point of time. First came the conduction systems—the attempt to substitute the earth and bodies of water in place of the connecting lines. Then came the induction systems, taking advantage of those peculiar electrical phenomena known as electrostatic and electrodynamic induction: here the substituted medium was the ether—that invisible, intangible substance which is supposed to fill all space. Last came the radiation systems, which also make use of the ether, but in a different way, namely, by disturbing it in such a manner as to produce far-reaching waves which can be detected at distant points. It is the last type, known as *radiotelegraphy*, which is today paramount, having superseded the other two by reason of its superior utility and effectiveness. Its startling development during the past ten years may justly be called a "fairy tale of science." The earlier systems are important, however, as they mark the birth and the development of an idea.

CHAPTER I

EARLY FORMS

Conduction Systems. The essential feature of all conduction systems is that *some other form of material conductor is substituted for that of wires.* These substitutes have been in all cases either earth or bodies of water, because they are the only natural conductors which are sufficiently common and extensive to be utilized.

Work of Steinheil. Today it seems glaringly obvious that the earth may be used as a conductor, but in 1838 when Steinheil, a Bavarian, accidentally discovered this fact, it created quite a sensation. He had been experimenting with the steel rails of a railroad trying to utilize them as substitutes for the wires of a telegraph circuit, but was unable to obtain sufficient insulation. He was surprised to discover, however, what a high degree of conductivity the earth possessed, and was led to conceive that he might employ it instead of the return wire hitherto used. He made the experiment, and with complete success, thus introducing into telegraphy one of its most important features—the earth circuit. Expanding the idea, Steinheil wondered if it were not possible to telegraph through the earth without using metallic conductors at all. This experiment, which was successful over very short distances, is said to have been the first attempt to telegraph without wires. Steinheil, however, being unable to signal farther than 50 feet, gave up this method, convinced that it was inexpedient for telegraphy.

Morse System. S. F. B. Morse, who is famed as the inventor of wire telegraphy and of the code which still bears his name, was, by a strange coincidence, also one of the pioneers of telegraphy without wires. In 1844 he addressed a letter to Congress in which he related his experiments in this field and gave an interesting account of his inception of the idea. A portion of the document, considerably abridged, is as follows:

> In the autumn of 1842, at the request of the American Institute, I undertook to give to the public in New York a demonstration of the practicability

> of my telegraph, by connecting Governor's Island with Castle Garden, a distance of a mile; and for this purpose I laid my wires properly insulated beneath the water. I had scarcely begun to operate, and had received but two or three characters, when my intentions were frustrated by the accidental destruction of a part of my conductors by a vessel which drew them up on her anchor and cut them off. In the moments of mortification I immediately devised a plan for avoiding such accidents in the future, by so arranging my wires along the banks of the river as to cause the water itself to conduct the electricity across. The experiment, however, was deferred until I arrived in Washington; and on Dec. 16, 1842, I tested my arrangement across the canal, and with success. The simple fact was then ascertained that electricity could be made to cross a river without other conductors than the water itself; but it was not until the last autumn that I had the leisure to make a series of experiments to ascertain the law of its passage. The diagram, Fig. 1, will serve to explain the experiment.
>
> *A*, *B*, *C*, *D*, are the banks of the river; *N P* is the battery; *G* is the galvanometer; *W W* are the wires along the banks, connected with copper plates *f*, *g*, *h*, *i*, which are placed in the water. When this arrangement is complete, the electricity, generated by the battery, passes from the positive pole *P* to the plate *h*, across the river through the water to plate *i*, and thence around the coil of the galvanometer to plate *f*, across the river again to plate *g*, and thence to the other pole of the battery *N*.

Morse here appends a table of his results, "showing," as he says, "that electricity crosses the river, and in quantities in proportion to the size of the plates in the water. The distance of the plates on the same side of the river from each other also affects the result." This distance he states elsewhere should be three times greater than that from shore to shore across the stream.

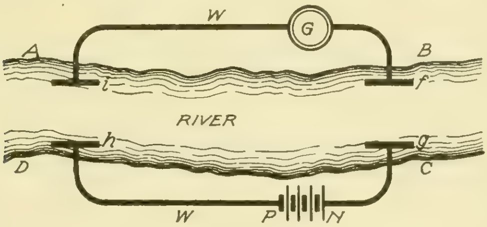


Fig. 1. Experiment of Morse

Morse's plan contains in a simple form all the essential features of all later endeavors to telegraph by the conduction method whether utilizing water or earth as the medium. Lindsay, Highton, Dering, Stevenson, Preece, Smith, and others subsequently worked out more elaborate and extensive methods all resting primarily on the same principle as above. None of them succeeded in signaling much farther than three miles. These early results indicate the inherent limitations which have ever remained as insurmountable difficulties to the commercial adoption of this form of wireless telegraphy.

Induction Systems. Induction is an electrical influence exerted by a charged body or by a magnetic field on neighboring bodies without apparent communication. The laws of it are well known to electrical science through the classic researches of Faraday. Induction comprehends two classes of phenomena known, respectively, as *electrostatic induction* and *electrodynamic induction:* the former is that property of the electrostatic field which produces an electric charge in a conductor when brought into the said field; while the latter is that property of the magnetic field by virtue of which electromotive forces are created in conductors by a relative movement between said field and such conductors. Without attempting to go further into the matter here, it suffices to say that investigators were not slow in appreciating that induction offered a means of communication which could be classified as "wireless."

Dolbear System. What is now generally considered to be an extreme case of electrostatic induction is the remarkable system of wireless communication invented by Prof. Dolbear of Tufts College, Boston, in 1882. This system is of especial historical interest owing to its startling resemblance to the system devised later by Marconi. Dolbear's invention may be best explained by referring to Fig. 2. The left side represents the transmitting circuit and the right, the receiving circuit. *B* is a battery connected through a carbon transmitter to the primary winding of an induction coil, the secondary terminals, *A* and *C*, of which are connected, respectively, with an elevated wire and the ground. The receiving end consists essentially of a similar elevated wire *A* connected to one terminal of a telephone receiver, the companion terminal of which is connected directly with the earth. The higher these wires are raised, the farther signals can be transmitted, so that Dolbear was prompted to attach them to kites. This is a curious anticipation of Marconi's antennae. Dolbear later made many modifications in his apparatus in an endeavor to reach greater distances by employing condensers raised to a considerable height and charged by batteries; but the system remained in all important respects the same as shown.

The apparatus works as follows: The diaphragm of the telephone transmitter is set into vibration by talking or whistling, thereby producing variations of resistance in the powdered carbon; this constantly varies the amount of current which flows into the induction coil; and consequently the wire *A* is charged to potentials which are constantly fluctuating in value, the degree of fluctuation depending on the degree of variation of resistance in the transmitter. The wire *A′* at the receiving station follows by electrostatic induction all the fluctuations of *A*; and with every change of potential, currents flow between *A′* and the ground through the telephone receiver *R*. The latter consequently repeats all the vibrations set up in the transmitter, and the corresponding sound is reproduced. This particular method of operation is telephonic; but it will be seen that the same, or rather better, results could be obtained by a Morse key and telephonic receiver.

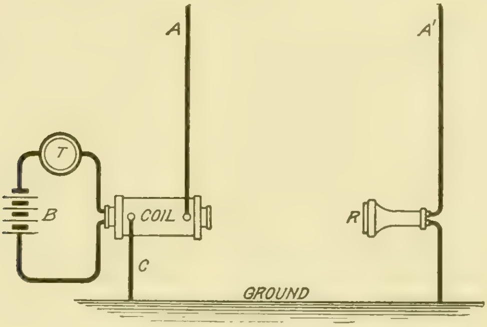


Fig. 2. Diagram of the Dolbear System

Edison System. Edison patented, in 1885, a system of inductive telegraphy, the particular purpose of which was to effect communication with moving trains. The ordinary telegraph wire, which commonly runs parallel to a railroad track, was utilized for one of the inductive circuits, and the train was equipped with another. The latter consisted mainly of a large, metallic condensing plate set on the roof of the car and connected to the secondary terminals of an induction coil, to the primary terminals of which were connected suitable transmitting and receiving instruments. When the Morse key in the primary circuit was depressed, the large condensing plate received static impulses and these acted inductively on the neighboring telegraph wire, which thereby received and conducted equivalent impulses to the nearest station equipped with proper receiving instruments. Or in case another train equipped as above were traveling on the same track, it could pick off the message inductively from the telegraph wire. In this manner two moving trains might communicate. This ingenious system was put into practical operation on the Lehigh Valley Railroad in 1887, and worked with undoubted success; but from a business point of view it proved a failure as there was no public demand for such service.

Work of Preece. One of England's most successful investigators in the field of wireless telegraphy was Sir Wm. Preece, chief electrician of the British Postal Telegraphs. He performed numerous experiments which added greatly to the theory of all forms of inductive and conductive communication. One of his most successful achievements was to effect inductive communication between Gloucester and Bristol on the banks of the Severn, a distance of nearly five miles. Parallel to the two shores were stretched on telegraph poles two closed wire circuits extending about 14 miles each. One of these circuits was traversed by a rapidly interrupted current of about .5 amperes. A telephone receiver inserted in the companion circuit responded to the frequency of the current in the other by a continuous sound upon pressure of the transmitting key. This form of communication was at one time resorted to quite frequently between stations separated by bodies of water under which it was inexpedient to lay cables.

Such systems may be characterized as "wireless" only through courtesy, since they demand an amount of wire which far exceeds that required by any ordinary wire system covering the same distance; they come under the classification of wireless telegraphy, however, since the wire conductors are not continuous, some other medium being interposed.

In the year 1885, Preece carried on very extensive investigations upon the possibilities of induction as an agency of communication, and summarized his observations as follows:

> Although communication across space has thus been proved to be practical in certain conditions, those conditions do not exist in the cases of isolated lighthouses and light-ships, cases which it was specially desired to provide for. The length of the secondary must be considerable, and, for good effects,

at least equal to the distance separating the two conductors. Moreover, the apparatus to be used on each circuit is cumbrous and costly, and it may be more economical to lay a submarine cable.

These conclusions are equally true to the present day. The necessity for a large base area remains the prohibiting factor in the adoption of electromagnetic induction systems. For a very painstaking review of the various early attempts at this form of telegraphy, the reader is referred to J. J. Fahie's excellent book, "A History of Wireless Telegraphy."

Summary. The conduction and induction methods of wireless telegraphy, although of great historical and experimental value, are of little practical value. Today their use is most exceptional because their utility is too limited—the supreme test for any system of wireless telegraphy being the test of long distance. They have been superseded by a type of wireless telegraphy which can achieve communication across an ocean if necessary—a type which is the product of an entirely different principle, the principle of electromagnetic radiation. In order to differentiate it from other forms of wireless telegraphy, this system is best denominated by the term *radiotelegraphy,* and a discussion of its underlying theory, its operation, and the arrangement of necessary apparatus will be found in the following chapters.

CHAPTER II

ELECTRIC WAVES

Electromagnetic Theory of Light. In order to understand radiotelegraphy with any degree of completeness one must first have a comprehension of the theory of electric waves, including the electromagnetic theory of light. This theory, with its verification, was one of the most notable scientific achievements of the last century. However, let it be remembered that, having adopted a working hypothesis—the most tenable one at present—to account for the ether and the *modus operandi* of ether waves, it is necessary as well as convenient to use the terms and implications of such hypothesis positively and with consistency throughout. Such unqualified use of terms might give foundation to the charge of scientific dogmatism were it not remembered at all times that we are dealing with a theory, generally accepted, it is true, but subject to the trials and mutations which such theories have undergone in the past. The reasonings from the working hypothesis are valid for the purpose for which they are here employed; but no true scientist will at present claim that such reasonings should or can be extended to the higher realm of absolute truth. In the words of H. Poincaré, "It matters little whether the ether really exists; that is the affair of metaphysicians. The essential thing for us is that everything happens as if it existed, and that this hypothesis is convenient for the explanation of the phenomena."

The electromagnetic theory of light was first completely stated in 1864, when James Clerk Maxwell, an English mathematician, sent to the Royal Society a paper entitled "A Dynamical Theory of the Ether," wherein he demonstrated his conviction that light and electricity were phenomena of a kindred nature—in fact, that light was an electrical manifestation. Maxwell's paper came as the result of a long series of investigations which had been carried on in two different departments of Physics—Optics and Electricity. These investigations had led on the one hand to a theory of a light-bearing medium called the *luminiferous ether*, and on the other hand to a theory of an electromagnetic medium also called the *ether*. Maxwell made a synthesis of these two theories, demonstrating that the hypothetical medium was the same in both cases, and that it was governed by electromagnetic laws.

The Luminiferous Ether. When we observe that light takes time to travel from place to place, and that it comes to the earth from the sun and stars across vast spaces which are not, so far as we know, filled with tangible matter, the inference necessarily follows that light is either a substance transmitted bodily, like a stone hurled from one place to another, or a physical state propagated through a stationary medium in the form of waves. Various investigators have demonstrated that light is a phenomenon of the latter description—that it is a physical state, or change of state, propagated through a stationary medium in the form of undulatory waves, the velocity of the waves being approximately 186,500 miles per second. Investigators agreed to call this medium the ether, prefixing the adjective "luminiferous" which means "light-bearing." They had neither seen nor felt the ether—directly or indirectly—but they reasoned that the ether must exist, else the facts of Optics were inexplicable. They held that it must be some peculiar form of matter which interpenetrated all ordinary forms of matter, and must also be distributed everywhere throughout the space of the universe. Up to Maxwell's time, however, they knew almost nothing of the ether itself, except that it behaved like an incompressible liquid, extremely tenuous but exceedingly rigid, and that the waves were of the kind classed as "transverse."

The Electromagnetic Medium. In the department of Electricity a theory of an electromagnetic medium had also grown up, following on the researches of Ampère, Henry, and Faraday. The fact that electrified bodies or magnets attracted or repelled each other at a distance, and that electric currents could create other currents in wires at a distance, and that these actions were not fundamentally dependent upon the presence of any material substance in the space between, led these investigators to conceive that there must be an electromagnetic medium by means of which such actions were transmitted across apparently empty spaces. They named this medium the ether, the same name adopted by investigators in the department of Optics; but it was a long time before anyone even surmised that there was any kinship between the luminiferous medium and the electromagnetic medium.

Work of Faraday. The first man to hint at the above possibility was Faraday, who, in 1845, discovered the singular fact that the magnet exercises a peculiar action on light, the plane of polarization of a polarized beam being rotated when the beam passes along a magnetic field. This seemed to show that there was some relation between electricity and light. Faraday persevered in these experiments. He wrote a paper entitled "Thoughts on Ray Vibrations" wherein he expressed his belief that radiation of all kinds—light, heat, etc.—were due to a high species of vibration of the lines of force in the magnetic field. Faraday's speculations may be said to have been the inception of the electromagnetic theory of light; he is indeed entitled to a large share of the credit; but his were only speculations, unformulated and incomplete, and it remained for another man to elaborate them into a complete theory mathematically demonstrable.

Work of Maxwell. When Maxwell, in 1864, sent his paper on "A Dynamical Theory of the Electromagnetic Field" to the Royal Society, one of his first steps was to acknowledge his debt to Faraday. He writes, "The conception of the propagation of transverse magnetic disturbances to the exclusion of normal ones is distinctly set forth by Prof. Faraday in his 'Thoughts on Ray Vibrations.' The electromagnetic theory of light as proposed by him is the same in substance as that which I have begun to develop in this paper, except that in 1846 there was no data to calculate the velocity of propagation." Maxwell then proceeds to give new equations to express the relations between the electric and the magnetic displacements in the medium and the forces which result from them. He shows that when magnetic methods of measurement are used, the unit of electricity arrived at has a certain value; but when purely electrical methods are used the unit proves to have a different value. The relation between these two units is dependent on the "electric elasticity" of the medium, and when measured proves to be a certain velocity—186,500 miles per second. This velocity, in other words, is that velocity with which an electromagnetic disturbance is propagated through the electromagnetic field. It will be remembered that the velocity of light was already known to be about 186,000 miles per second. Maxwell comments on the startling similarity as follows: "This velocity is so nearly that of light, that it seems we have strong reason to conclude that light itself (including radiant heat, and other radiations, if any) is an electromagnetic disturbance in the form of waves propagated through the electromagnetic field according to electromagnetic laws." In short, Maxwell's theory assumes that the entire material universe lies in one all-pervading electromagnetic field, called for convenience *the ether*, and if this field be disturbed at any point, the disturbance is propagated throughout the field in the form of waves. All those forms of radiant energy which we call light, heat, etc., are in reality electromagnetic disturbances propagated in the form of electromagnetic waves.

Once an electromagnetic field is established, any change which alters the prevailing conditions is said to be an electromagnetic disturbance. When a current of electricity increases in strength, the field around it increases also, the lines of force spreading out from the conductor like ripples in a pond; but when the current is decreased, the lines of force contract, closing in around the conductor, and the energy of the field shrinks back into the system. If this process be augmented so that the periodic reversals of current produce oscillations of extremely high frequency, then, at each reversal, part of the energy of the field radiates off into the surrounding medium as electric waves and only part of it returns into the system. The frequency with which such periodic reversals of current take place determines the distance between the crests of the waves radiated into space from such a system. Waves created in the ether by this means are called *electric*, or *Hertzian, waves*, after the German physicist, Heinrich Hertz. Before entering upon a more detailed consideration of waves of this character, the subject of waves in general will be considered.

Nature of a Wave. When a disturbance is made at any point in an elastic medium, the particles of the medium are set into vibration and the vibrations are passed on to the neighboring particles, so that waves are formed; and these waves travel with a uniform velocity depending on the nature of the medium, with a result that the disturbance is propagated to considerable distances from its point of origin. There are in general two classes of waves, known as *longitudinal* and *transverse*, the distinction between them depending on the direction in which the particles vibrate. When the particles vibrate along the line in which the disturbance is traveling, the wave is said to be longitudinal; when the particles vibrate at right angles thereto, the wave is said to be transverse. The general equation for determining the velocity of waves of either class is

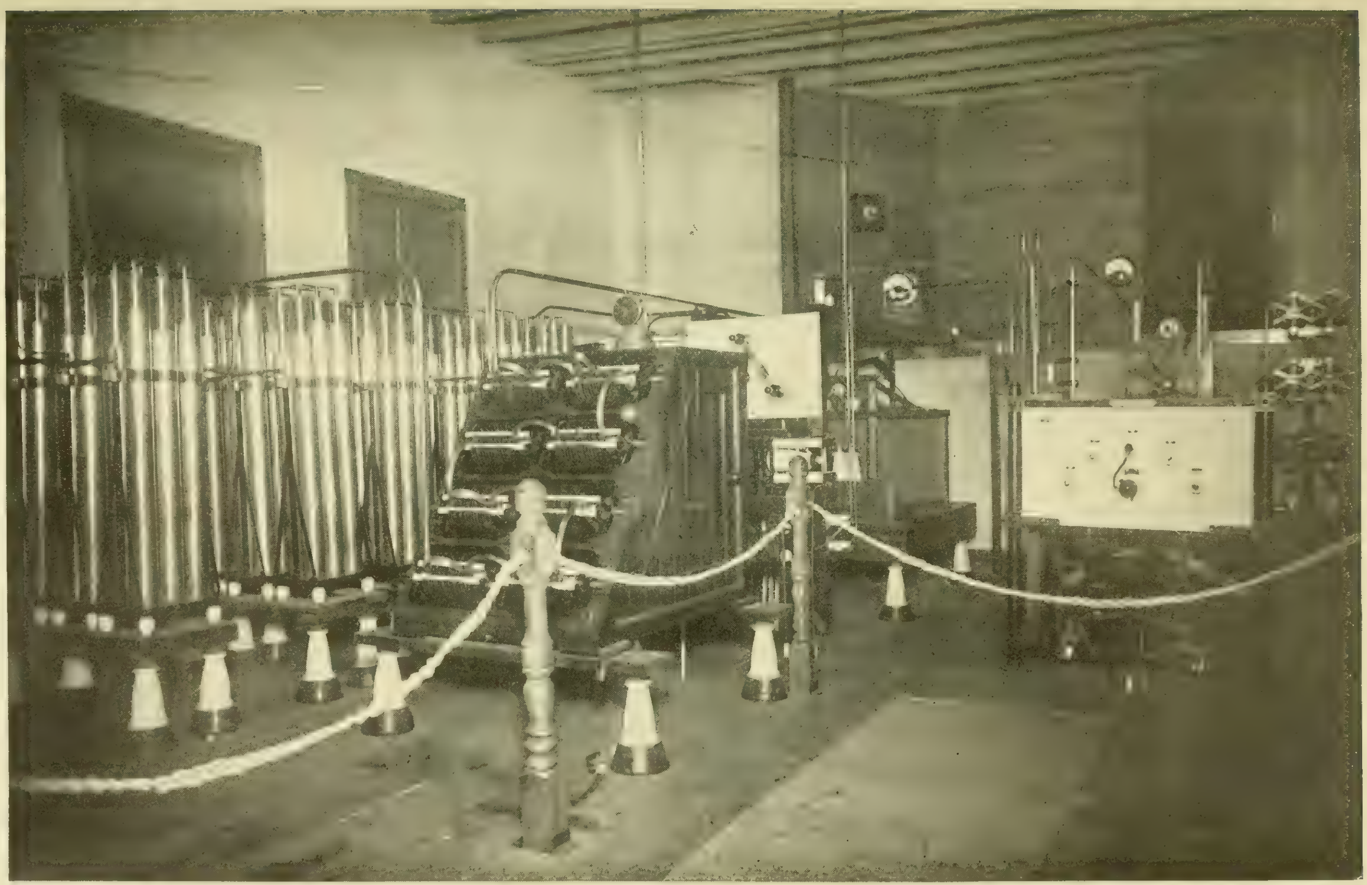
$$v = ln$$

where v stands for the velocity, l for the wave length, and n for the frequency, or number of vibrations per second.

This equation holds equally true for ether waves which manifest themselves as light, and for the longer waves produced by high-frequency oscillations of an electric current, both of which are of the transverse variety. Indeed all forms of radiant energy are, according to the present belief, due to ether waves, differing from one another only in length. As the velocity of propagation is the same for all—namely, 186,000 miles per second—the frequency varies through a wide range. Ether waves varying between certain definite lengths are visible and produce the sensation of light; others much longer falling upon matter raise its temperature, thus manifesting themselves as heat; still others, of a wave-length extremely small even in comparison with visible rays, are capable of penetrating matter as X-rays; and others again, of a length of half a mile or more, are flashed across the Atlantic, conveying intelligence from the Old World to the New.

As there are many methods of producing waves in gross matter, so also are there many methods of producing waves in the ether. The production of electromagnetic waves of a length measuring from a few inches to many rods need only concern us here, as it is with the production of such waves that the science of radiotelegraphy deals. As before stated, a part of the energy of a very rapidly alternating current is radiated off into space in the form of electric waves. Under what physical conditions such disturbances are created will now be considered.

Electric Oscillations. If a charged condenser, or Leyden jar, is discharged through a conductor of *high resistance*, the opposing polarities slowly neutralize each other by a current flowing in one direction. If, however, the condenser is discharged through a conductor of *low resistance*, such as a coil of wire of a few turns, the effect is wholly different. Under these conditions the discharge consists of a number of excessively rapid oscillations of the nature



GIANT TRANSMITTER AT THE WIRELESS STATION, SAYVILLE LONG ISLAND
Photograph by Underwood & Underwood, New York

of a high-frequency alternating current, caused by the self-induction of the coil, in consequence of which the current once set up tends to persist. The first rush of current more than empties the condenser, and charges it to the opposite polarity; then follows a series of similar discharges of diminishing amplitude until the energy of the charge is entirely dissipated. This process is represented in Fig. 3.

The spark produced by the discharge of a condenser under these conditions appears to the eye as a single flash, due to the rapidity with which the successive discharges follow one another. In reality it consists of several distinct sparks lasting but an exceedingly small fraction of a second.

The law governing condenser discharges is as follows: *If a condenser of capacity* K *is discharged through a resistance* R *and self-induction* L, *the result is a uni-directional discharge or a series of oscillations according as* R *is greater or less than* $2\sqrt{\frac{L}{K}}$.

A rapid oscillatory discharge sets the electromagnetic medium in vibration much as a tuning fork sets the air in vibration in producing sound-waves. Such discharges provide a simple means for creating electric waves in the ether. An understanding of condenser action is, therefore, of great importance in a comprehension of the principles of radiotelegraphy.

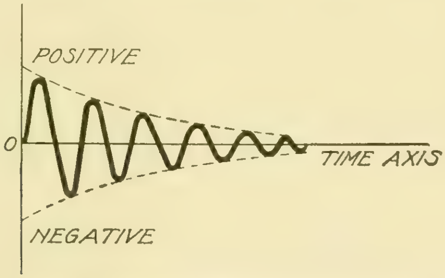


Fig. 3. Curve Representing an Oscillatory Discharge

The oscillatory nature of condenser discharges was known when Maxwell promulgated his electromagnetic theory, but it was not until twenty-five years after the announcement of the theory that scientists were able to detect the presence of electric waves. They knew the conditions under which such waves should arise, but none were able to devise a means to demonstrate their presence. It remained for Heinrich Hertz, a pupil of the illustrious von Helmholtz, to solve the mystery and give experimental verification to a theory which must ever remain one of the greatest achievements of inductive reasoning. Hertz succeeded not only in producing and detecting electric waves, but in demonstrating that such waves possessed all the essential characteristics of light.

The Work of Hertz. It was in 1888 that Hertz, then thirty years old and professor of Physics in the University of Bonn, carried on the epoch-making series of experiments which have proven to be the foundation of the art of radiotelegraphy. His apparatus was of the simplest construction. To generate electric waves he employed what is now known as a *Hertz oscillator*, Fig. 4. This consists of two metallic conductors in the shape of plates or spheres, each attached to a small rod terminating in a polished metal ball. These were connected to the secondary terminals of an induction coil and the two balls brought into close proximity, thus forming a small spark gap. It will be seen that the arrangement has the essential features of a condenser whose plates are widely separated and whose dielectric extends into the surrounding air. When the charge is accumulating on the large metallic plates, a strong electric

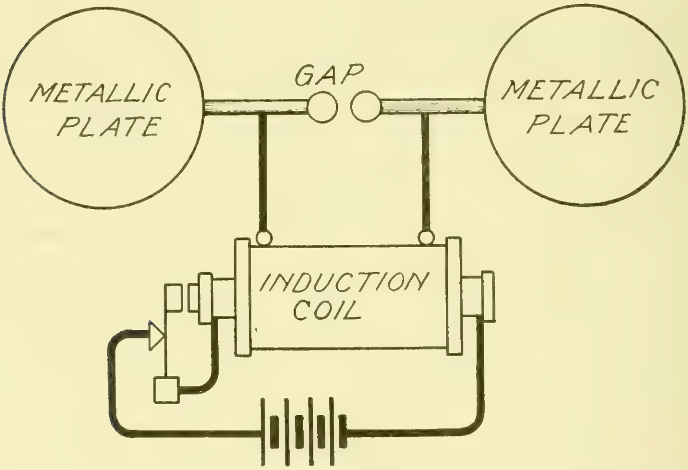


Fig. 4. Hertz Oscillator

displacement is set up between them, and, as the potential difference rises, a point is reached where the insulation of the air gap breaks down and a spark passes across the gap. During the passage of this spark the air becomes highly conductive and the whole oscillator becomes one conductor for the time being. The potential difference between the charged plates immediately begins to equalize itself, after the manner of all oscillatory condenser discharges, by a series of rapidly damped surges, and with every oscillation a wave is radiated into space. The waves emitted by a device of this character are intermittent, each complete discharge of the oscillator sending out a rapidly damped train, or group, of waves. The frequency with which such trains follow one another depends upon the frequency of the charging source.

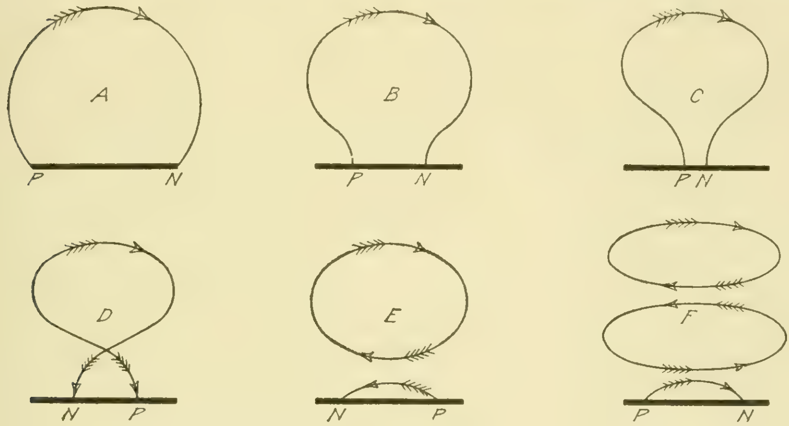


Fig. 5. Formation of Closed Loops of Electric Strain

It cannot be said that the exact sequence of events in the formation of an electric wave is definitely agreed upon, further than that the production consists in sending out closed loops of force as shown by Hertz, Dr. F. Hack, and others. The subject is very difficult to present briefly, but an idea of the process may be had by reference to Fig. 5.

The curved line represents the form and the direction of one of the many lines of electric strain existing between the two plates of a Hertz oscillator. Every line of electric strain according to the electronic theory of electricity must be a closed line or loop, or else must terminate on an electron and a co-electron. The figures *A*, *B*, *C*, *D*, *E*, and *F* represent the successive stages in the production of closed loops of electric strain. As the charges oscillate to and fro the lines of electrostatic strain are crossed, making a closed loop which is immediately pushed outward by the following loop; with the result that the direction of strain around each loop is alternately in one direction and in the other, as shown in *F*. In addition to these lines of electrostatic strain there are at right angles to them other self-closed lines of force of a magnetic nature, due to the current passing during discharge. These magnetic rings of flux alternate in their direction at each oscillation, thus forming a series of closed loops of magnetic flux co-axial with the oscillator. Hence we are called upon to imagine the space around a Hertz oscillator as filled with concentric rings of magnetic flux periodically reversing in direction and having their maximum values at instants when the electrostatic strains are at their minimum values. These complementary modes of energy periodically varying in regard to time and space form an electric wave.

Energy of an Oscillator. As a portion of the energy imparted to an oscillator in the form of an electric charge is expended in heating the metallic balls, in creating a bright light, and in producing a noise at the discharge, it is evident that the entire energy of the system is not expended in the formation of electric waves. The total amount of energy which it is possible to potentially store in an oscillator in the form of electrostatic stress depends on its electrical capacity, and is equivalent to the amount of energy which could be stored in a condenser of the same capacity. The storage of energy in a condenser is proportional to the square of the voltage to which it is charged; which is another way of saying that a very great amount of energy could be stored in a very small condenser if it were possible to maintain the insulation under exceedingly high potentials. The dielectric strength of the material used for the dielectric thus places a limit upon the amount of energy it is possible to store in such a device. A small oscillator could likewise have a large amount of energy imparted to it by enlarging the spark-gap enough to allow a higher potential to be reached before the insulation of the gap breaks down, were it not for the fact that the increased resistance of the lengthened gap renders the spark non-oscillatory.

A limit is therefore placed upon the potential which it is practicable to employ in the charging of oscillators or any form of condenser. As the capacity of a condenser increases in direct proportion to the area of its plates—other factors remaining the same—it is evident that the dimensions of an oscillator of the Hertz type determine the amount of energy it is possible to utilize in the generation of electric waves.

Hertz Resonator. The most important contribution of Hertz to the subject of electric waves was the discovery of a simple means for detecting the presence of such radiations. The fundamental character of the discovery is apparent when it is observed that the device consists simply of a single turn of wire forming a ring, provided with a spark gap between two metallic knobs, the distance separating these terminals being adjustable by a screw. The device, called a *resonator,* is shown in Fig. 6. Hertz discovered that electric waves falling upon such a conductor were capable of inducing therein alternating currents of the same frequency. By holding his resonator within a few yards of an active oscillator he found that it became the seat of induced secondary oscillations which were strong enough to be manifested by minute sparks visible between the metallic balls. Following up this clue he carried on a very extensive series of experiments, all tending to prove that such waves possessed all the characteristics of light—that they were indeed but "invisible light." Hertz' resonator may be said to be the first "wireless detector" known. The further development of this pregnant idea plays an important part in the evolution of the systems of wireless telegraphy.

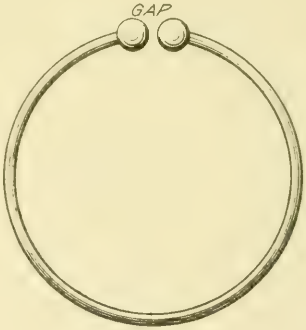


Fig. 6. Hertz Resonator

Resonance. A definite period of vibration is characteristic of many things in nature, including all sonorous bodies such as strings under tension, as in the case of the piano and all stringed instruments; confined portions of air, as exemplified by the organ pipe; and in fact all bodies which, when displaced by the application of an external force, tend to return by virtue of their elasticity and execute free vibrations until they gradually come to rest. If very feeble impulses be applied to a pendulum at rest at intervals exactly corresponding to its natural period of vibration, it may be made to swing through an arc of considerable amplitude. Bodies capable of executing vibrations by virtue of their own resiliency may likewise be set into powerful vibration by a series of impulses keeping time with their own natural period. Thus a tone from a violin may draw forth a responsive note from a piano, and by the same reason a piano will often set into sympathetic vibration some fixture or article of bric-a-brac. Also impulses communicated through the air from a sounding tuning-fork and falling upon another of the same pitch, will cause the latter to hum a note in unison. This phenomenon is called *resonance.* Resonance is thus an increase, or amplification, of a periodic motion by an intermittent force of the same time-period.

Resonant effects are not confined to the vibrations of gross matter, but may also be observed in connection with the flow of electricity in a circuit. This would seem to indicate that an electric circuit possessed something analogous to a natural period of vibration—which is the case. This time-period is due to certain characteristics of the circuit, namely *capacity,* and *inductance.* The quantity of electricity required to charge a conductor up to unit potential or, in other words, the ratio of the charge on a conductor to its potential, is called *capacity.* The unit employed to measure capacity is the farad. *Inductance* is that quality of an electric circuit by virtue of which the passage of an electric current is necessarily accompanied by the absorption of energy in the formation of a magnetic field. The analogy to mechanical inertia is very close, and, for convenience, inductance may be thought of as electromagnetic inertia by reason of which an electric current resists any sudden change. The unit of inductance is the henry. In all circuits possessing capacity and inductance there is a storage of electrostatic energy due to the potentially charged capacity, and a storage of electromagnetic energy due to the formation of the magnetic field by the current. Any electrical change taking place in such a circuit requires a readjustment of this stored energy. Such an adjustment takes place in the form of an oscillatory current of diminishing amplitude until equilibrium is restored. The time-period of such oscillations of energy is dependent upon the capacity and the inductance of the circuit, and is expressed by the equation

$$T = 2\pi\sqrt{LK}$$

where L is the inductance in henries, and K is the capacity in farads. The number of such oscillations per second, *i. e.*, the frequency, is, therefore, $n = \frac{1}{T}$. For purposes in connection with wireless telegraphy this equation is better expressed in microseconds, microhenries, and microfarads.

The phenomena of electrical resonance were first illustrated by Sir Oliver Lodge in his well-known experiment with his so-called *syntonic jars.* Two Leyden jars, Fig. 7, are placed a short distance apart. A bent wire connected to the outer coating of one serves as a discharging circuit (as shown) with a short air gap between polished knobs at the top. A circuit of wire whose inductance is rendered adjustable by a sliding cross-piece—making connection between two conductors—is connected permanently with a second jar. This jar is also provided with a spark gap formed between the outer coating and a small piece of tin-foil extending from the inner coating over the lip of the jar to within a short distance of the outer coating. By continually discharging the first jar by connection with an induction coil or other suitable source of high potential, and by manipulating the sliding cross-plate in the circuit of the other jar, a point may be found where the latter will also discharge in syntony with the first. The two circuits are then said to be in tune, in syntony, or in resonance. When the product of inductance by capacity is the same for two circuits, they have the same natural period of oscillation.

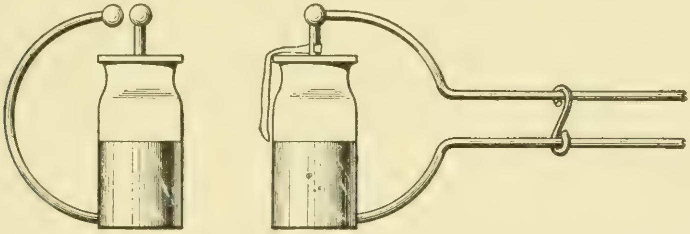


Fig. 7. Lodge Syntonic Jars

As any circuit possessing inductance and capacity tends to oscillate electrically at its own frequency, it becomes the seat of an induced oscillatory current when subjected to the influence of electric waves of that frequency, each wave giving a slight impulse to the readily excited oscillations, with the result that the induced electromotive forces will be amplified in intensity, just as the swing of a pendulum is amplified by the application of properly timed, though feeble, touches. Circuits possessing inductance and capacity connected in series are thus capable of being "tuned" to a required frequency by a proper adjustment of these two factors. Such circuits are called *oscillatory circuits* and may be of many forms, but can be classified under two heads known as *closed* oscillatory circuits and *open* oscillatory circuits. Those circuits having their capacities in the form of condensers whose capacity areas are closely associated are called "closed," and those having their capacity areas widely separated in such a manner as to cause the field of electrostatic stress to extend out into the surrounding space are called "open." In the first, Fig. 8, the capacity is represented by the two metallic disks separated by a dielectric of air, and connected by a circular wire representing the inductance of one turn, while the "open" type, Fig. 9, is shown by the two metallic capacities connected by a rod which is cut in two at the center to form a gap. Either may or may not have an air gap introduced therein.

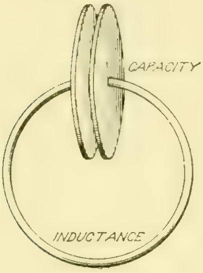


Fig. 8. Closed Oscillatory Circuit

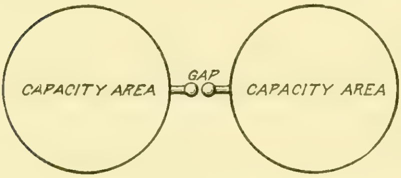


Fig. 9. Open Oscillatory Circuit

The similarity to the Hertz oscillator and resonator is apparent at a glance. This is, indeed, more than a similarity, for the Hertz oscillator was nothing more than an open oscillatory circuit, and his resonator a closed circuit of the same variety. By separating the plates of a condenser after the manner of a Hertz radiator, thereby forming an open oscillatory circuit, a large part of the energy of the charge is radiated away in the form of electric waves by reason of the dielectric extending out into the surrounding air. Circuits of this type are, therefore, excellent radiators but not very persistent radiators, because the oscillatory current is damped quickly by the rapid dissipation of energy in the radiation. Conversely, circuits of the closed type are persistent vibrators, but poor radiators. The train of waves emitted by the open type may be compared to the note given forth from a piano string when the finger is immediately removed from the key allowing the damper to rapidly extinguish the vibration. The closed type is comparable to a note struck on the same instrument but with the damper raised by the sustaining pedal. As it requires an increment of time to start oscillations in a tuned circuit, it is obvious that the closed type is preferable if it can be made to radiate sufficiently. If the damping of the oscillations in a radiator takes place too quickly, the energy of the charge will be dissipated at the first or second surge, in which event the exact tuning of a resonating circuit is unimportant. With a persistent oscillator, however, syntony between the two circuits is of the utmost importance, as otherwise the exciting circuit will tend to destroy at one moment the oscillations it set up a moment earlier. Syntony is of great practical value in the application of Hertzian waves to wireless telegraphy in that it permits of selective signaling to a certain extent by the employment of different wave-lengths, or the tuning of a receiving station to the frequency of a sending station.

Wave-Lengths. As before mentioned, the waves created by a Hertz oscillator are of very much lower frequency and are proportionally longer than light waves, but their velocity is identical. Furthermore, the relation between the velocity of propagation, frequency, and wave-length of ether waves was shown to be expressed by the equation

$$v = ln$$

In order to obtain numerical values for these quantities, it is evident that the value of v must be determined by reference to the best available experimental data. Numerous investigators have agreed upon 3×10^{10} centimeters per second as representing the most probable value for this constant. Knowing this, and by assigning the correct values to the factors *capacity* and *inductance* in determining the natural frequency, it becomes a simple matter to calculate the length of wave emitted by a radiator; and, conversely, by employing the proper capacity and inductance a radiator may be constructed to give any desired wave-length within wide limits. Capacity and inductance may be considered to be the electrical dimensions of an oscillator, and they determine the length of wave emitted, just as the note emitted from an organ pipe depends upon the dimensions of such a pipe.

The waves created by Hertz with various forms of his oscillator varied between a few inches and a few feet in length. He determined these lengths not only by mathematical computation as explained above, but by direct experimental test. He set up at the far end of his laboratory a large sheet of metal to reflect back the waves, and then went about the room with his resonator, exploring the space to find at what points sparks were produced. He found that when waves are thus reflected back upon themselves there are nodal points, just as there are nodal points in sound-waves and in light-waves when similarly reflected. Measuring the distances between these nodal points he was able to determine the wave-length precisely.

With the simple instruments at his command Hertz carried on many other experiments which are little short of beautiful in their adaptation of means to ends; but we cannot go into them here more than to say that they all tended to prove the main contentions of Maxwell's theory. The unqualified success of these experiments won the admiration of scientists all over the world. But few, if any, realized at the time that Hertz, in addition to giving indisputable proof to Maxwell's famous hypothesis, had also laid the foundations for a new and triumphant system of wireless telegraphy.

CHAPTER III

THE DEVELOPMENT OF RADIOTELEGRAPHY

It is evident that when Hertz constructed an apparatus which could transmit electrical manifestations to a distance, without wires, he possessed the elements of a system of wireless telegraphy. All signaling at a distance whether by wire or without, requires the presence of three fundamental factors: a device to produce the signal; a medium to carry the signal; and a device to receive the signal. Hertz' apparatus with its oscillator, electromagnetic medium, and resonator, easily fulfilled the requirements, and its use as a system of wireless telegraphy was merely a matter of time.

The main line of development was to be an extension of the distance over which signals could be transmitted; for as we have seen in the consideration of earlier systems—notably induction systems—distance is the important factor. Any system which cannot transmit messages to a considerable distance is of small practical service to the world. Hertz with his apparatus never succeeded in producing waves which were detectable at more than a score of meters or so; consequently we need not wonder that he never suspected that one of the largest fruits of his achievement was to be a system of wireless trans-oceanic communication. When asked by a civil engineer of Munich whether he thought telephonic communication could be effected by means of electric waves, he replied in the negative, as he considered that the alternations of current in the telephone were not of a nature to be detectable. He could not, of course, foresee the improvements which were destined to be made, rendering his apparatus immeasurably more sensitive and serviceable.

All the scientists of Europe were stirred by the announcement of Hertz' discoveries, and many set about to repeat the experiments. With so many minds bent upon a kindred purpose it is not surprising to learn that much new light was thrown upon the subject and many improvements made in the form and efficiency of the Hertz apparatus. Both the radiator and the detector were signally bettered.

The Righi Oscillator. One of the disadvantages of Hertz' radiator lay in the fact that the sparks in a short time oxidized the little knobs and roughened their surfaces, resulting in irregular action. Prof. Righi of Bologna overcame this difficulty by partly enclosing two metal spheres, *A* and *B* in Fig. 10, in an oil-tight case so that the outside hemispheres of each are exposed, the inner hemispheres being immersed in vaseline oil with only a minute gap between them. In a line with these spheres are ranged two smaller spheres, *C* and *D*, which form the secondary terminals of the induction coil. Thus three sparks are produced: one between *C* and *A*, another between *A* and *B*, and another between *B* and *D*. It is between *A* and *B* in the oil gap that the oscillatory spark takes place, the other two sparks serving merely to charge the large spheres. This arrangement not only produced a more constant spark by preventing the pitting of the electrodes but greatly extended the range of wave-lengths which it was possible to employ in investigations of this character. The dimensions of the oscillator could thereby be reduced and the amplitude of the oscillations greatly increased by reason of the fact that higher potentials could be reached before the energy was released by discharge. Righi obtained oscillations of a frequency of 12,000,000,000 vibrations per second by the use of small spheres *A* and *B* eight millimeters in diameter.

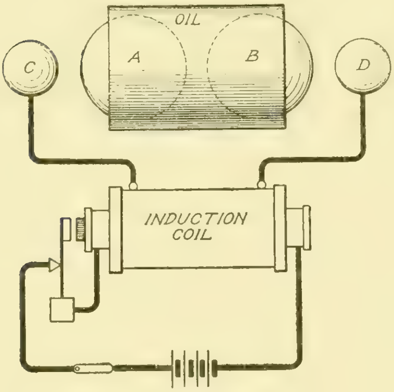


Fig. 10. Righi Oscillator

The Branly Coherer. The next important advance pertained to an improvement over the Hertz resonator as a means of detecting electric waves. It was based on the discovery of M. E. Branly and others, that the enormous resistance offered to the passage of an electric current by powders and metal filings is greatly reduced under the influence of electric oscillations. The resistance of such conductors may drop instantly from thousands of ohms to hundreds by the action of induced oscillations, retaining this conductivity until "decohered" by a mechanical blow. It will be readily seen that this provides a simple means of effecting the operation of a translating device by acting as a valve in turning on, as it were, a greater current in a local battery circuit. By utilizing this property of increased conductivity Sir Oliver Lodge succeeded in causing the deflection of a galvanometer. The device employed by Lodge consisted of a glass tube in the ends of which were sealed terminal wires connected to metallic electrodes of the same diameter as the tube, and between the electrodes was placed a small quantity of iron filings, as shown in Fig. 11. This device is known as a *coherer,* a name suggested by Lodge. In various modified forms the instrument has been employed up to the present day in different wireless systems. Its practical application will be fully considered later in connection with the work of Marconi.

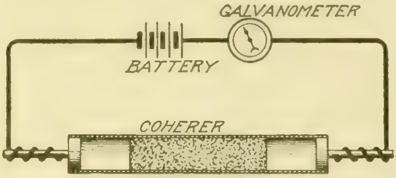


Fig. 11. Lodge Coherer

Radiotelegraphy First Suggested. As the Righi oscillator and Branly coherer were immeasurably more efficient than Hertz' corresponding apparatus, it necessarily follows that waves could be sent and detected over much longer distances and the time was getting ripe for the application of these devices to the purposes of wireless telegraphy. The first man to suggest this possibility is said to have been Sir Wm. Crookes, the eminent English chemist and physicist. In a magazine article which appeared in 1892 he made the following marvelous forecast of Radiotelegraphy:

> Rays of light will not pierce through a wall, nor, as we know only too well, through a London fog; but electrical vibrations of a yard or more in wave-length will easily pierce such media, which to them will be transparent. Here is revealed the bewildering possibility of telegraphy without wires, posts, cables, or any of our costly appliances. Granted a few reasonable postulates, the whole thing comes well within the realms of possible fulfillment. At present experimentalists are able to generate electric waves of any desired length, and to keep up a succession of such waves radiating into space in all directions. It is possible, too, with some of these rays, if not with all, to refract them through suitably shaped bodies acting as lenses, and so to direct a sheaf of rays in a given direction. Also an experimentalist at a distance can receive some, if not all, of these rays on a proper instrument, and by concerted signals, messages in the Morse code can pass from one operator to another.
>
> What remains to be discovered is—firstly, simpler and more certain means of generating electrical rays of any desired wave-length, from the

> shortest, say a few feet, which will easily pass through buildings and fogs, to those long waves whose lengths are measured by tens, hundreds, and thousands of miles; secondly, more delicate receivers which will respond to wave-lengths between certain defined limits and be silent to all others; and thirdly, means of darting the sheaf of rays in any desired direction, whether by lenses or reflectors, by the help of which the sensitiveness of the receiver (apparently the most difficult of the problems to be solved) would not need to be so delicate as when the rays to be picked up are simply radiating into space, and fading away according to the law of inverse squares. . . .
>
> At first sight an objection to this plan would be its want of secrecy. Assuming that the correspondents were a mile apart, the transmitter would send the waves out in all directions, and it would, therefore, be possible for anyone living within a mile of the sender to receive the communication. This could be got over in two ways. If the exact position of both sending and receiving instruments were known, the rays could be concentrated with more or less exactness on the receiver. If, however, the sender and receiver were moving about, so that the lens device could not be adopted, the correspondents must attune their instruments to a definite wave-length, say, for example, 50 yards. I assume here that the progress of discovery would give instruments capable of adjustment by turning a screw, or alternating the length of a wire, so as to become receptive of waves of any preconcerted length. Thus, when adjusted to 50-yard waves, the transmitter might emit, and the receiver respond to, rays varying between 45 and 55 yards, and be silent to all others. Considering that there would be the whole range of waves to choose from, varying from a few feet to several thousand miles, there would be sufficient secrecy, for the most inveterate curiosity would surely recoil from the task of passing in review all the millions of possible wave-lengths, on the remote chance of ultimately hitting on the particular wave-length employed by those whose correspondence it was wished to tap. By coding the message even this remote chance of surreptitious tapping could be rendered useless.
>
> This is no mere dream of a visionary philosopher. All the requisites needed to bring it within the grasp of daily life are well within the possibilities of discovery, and are so reasonable and so clearly in the path of researches which are now being actively prosecuted in every capital of Europe, that we may any day expect to hear that they have emerged from the realms of speculation into those of sober fact. . . .

The purposes and problems of radiotelegraphy are admirably stated in the above. Some of those problems have not even yet been solved, as we shall see. When Crookes wrote, the idea of radiotelegraphy was in the air, and many men indeed were striving to turn the possibility into a reality. Several Englishmen almost achieved the desired end, but, strangely enough, faltered or failed when success was within easy reach. Among these, mention must be made of Prof. D. E. Hughes, who, but for a combination of bad luck and human fallibility, might have been today the accredited discoverer not only of radiotelegraphy but of electric waves as well.

Work of Hughes. As far back as 1879, when experimenting with his celebrated microphone (which is in reality nothing other than a Branly coherer reduced to its simplest elements) Hughes observed peculiar electrical effects operating at a distance, and he concluded that they were due to invisible electric waves. He did not, however, so far as we know, relate these phenomena with the theories of Maxwell, as Hertz did, and was consequently at a loss to fully account for them. He investigated the subject for several years and actually succeeded in telephoning wirelessly over considerable distances. These experiments were repeated before Prof. Stokes, the president of the Royal Society, and Prof. Huxley; but these gentlemen expressed doubts as to the nature of the phenomena, with the result that Hughes became infected with their scepticism and abandoned his efforts, believing himself on the wrong track. If he had persisted in his researches he might have gathered the laurels that later went to Hertz and Marconi. It has been said that "Hughes' experiments of 1879 were virtually a discovery of Hertzian waves before Hertz, of the coherer before Branly, and of wireless telegraphy before Marconi and others," and the truth of the statement must be admitted to some extent.

Work of Lodge. Mention must be made of the great debt which radiotelegraphy owes to Sir Oliver Lodge for his many valuable contributions both to practice and theory. He has been in the forefront of every advance made in the science of radiotelegraphy, and might in all truth be called its patron saint. To him is due our knowledge of the principles of syntony which forms such a vital part of all modern systems. He was the first man to employ the Branly coherer as a detector of Hertzian waves, and while engaged in demonstrating the discoveries of Hertz was sending signals over distances measurable in hundreds of feet. That such signals could be utilized to convey intelligence by the simple application of the Morse telegraphic code did not occur to him; if he had realized this possibility he might have antedated Marconi's invention of wireless telegraphy.

Work of Marconi. Passing over Popoff, Rutherford, Jackson, Minchin, and others, several of whom did important and original work, we come to Marconi who, in the popular mind, is credited with the whole achievement of radiotelegraphy. It is true that

Marconi carried radiotelegraphy through to practical success; or, as A. T. Story puts it, "he carried forward into the domain of practical reality what had only floated indistinctly before the minds of others, or had served them for modest experiments." But as regards those vital and fundamental developments of theory and practice without which radiotelegraphy would still be a thing unknown, Marconi is only an able follower and not one of the pioneers. The history of radiotelegraphy might be shortly indicated by the following list of names: Faraday, Maxwell, Hertz, Righi, Lodge, Marconi. The theory of electric waves originating with Faraday and expanded by Maxwell, was experimentally demonstrated by Hertz. Then came Righi and Lodge with their improvements on the Hertz apparatus, greatly extending its sphere of utility; and finally Marconi, who brought together the results achieved by his predecessors and, adding something of his own—"a far-seeing initiative where others had not gone beyond timid projects or tentative research"—produced a successful system of wireless telegraphy. Marconi, who is an Italian by birth, first became interested in Hertzian waves when a student under Prof. Righi at the Bologna University. He was not long in seeing their possible application to telegraphy, and made some experiments with that purpose in view. Becoming convinced of the feasibility of the project, but finding no one in Italy ready to take it up, he set out for England to try his fortune. Arriving there, he applied to the Patent Office for protection on his ideas, and then took the proposition to Sir Wm. Preece, chief of the British Postal Telegraphs. Preece gave Marconi ready encouragement, and he was soon conducting experiments under the auspices of the British Post Office.

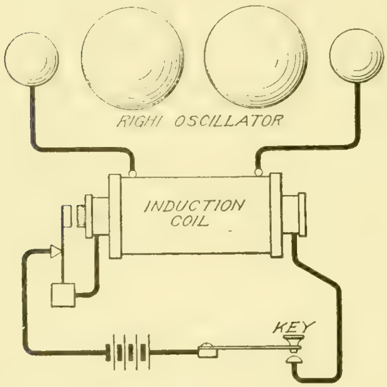
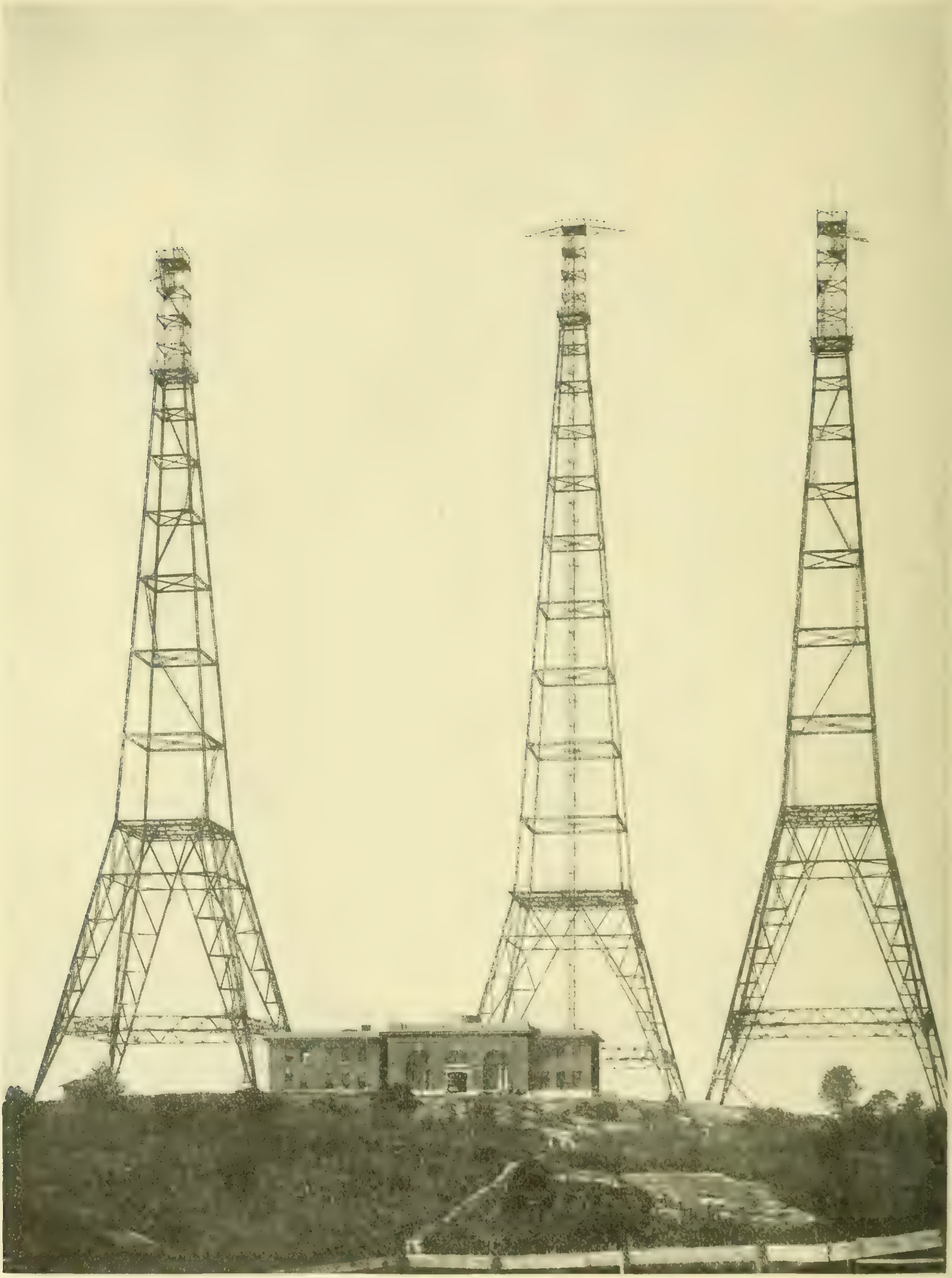


Fig. 12. Early Marconi Transmitter Circuit

Early Apparatus. The early apparatus of Marconi consisted essentially of a Righi oscillator and Branly coherer, disposed in suitable



NAVAL WIRELESS STATION AT ARLINGTON, VIRGINIA

The tallest tower is 600 feet high and the other two, 450 feet each. The power house is shown at the base of the towers. This station can send messages within a radius of 3000 miles

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circuits for generating and recording the flow of waves. The transmitting arrangement consisted of an induction coil producing the requisite high potential with which to charge a Righi oscillator, and a Morse key of heavy construction with which to break the primary circuit of the coil, connected with a battery of about five cells. The actual transmission of messages was effected by the intermittent movement of the Morse key which, upon completing the circuit, started the interrupter of the coil which remained in operation as long as the key was held down; thus the duration of waves from the oscillator was made dependent on the position of the key. It was thus possible by the proper manipulation of the key to send a series of long or short wave trains corresponding to the dots and dashes of the Morse alphabet. Fig. 12 represents diagrammatically these features of the sending station.

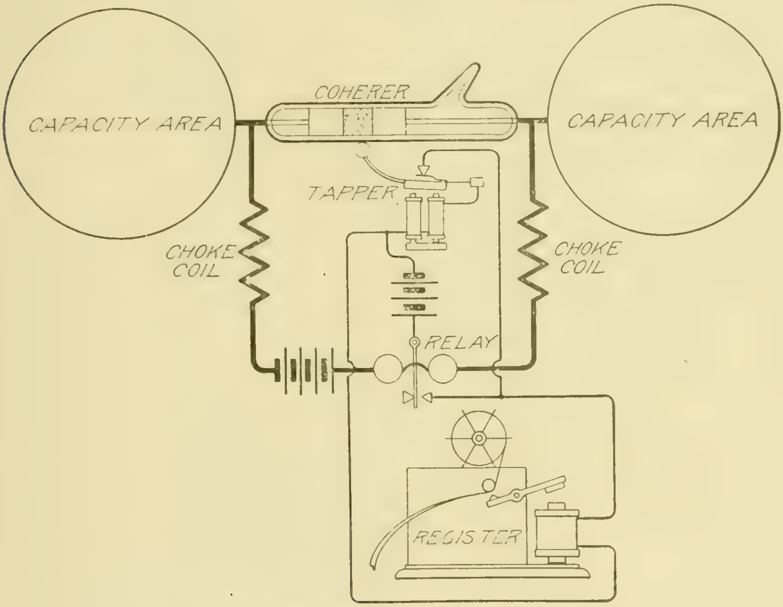


Fig. 13. Early Marconi Receiving Circuit

The receiving apparatus, indicated in Fig. 13, consisted principally of the Branly coherer somewhat modified in construction and associated with suitable auxiliary apparatus for recording the duration of the received wave trains in the form of dots and dashes upon a moving paper surface after the manner of the Morse recorder, well known in wire telegraphy. As the coherer retains its low conductivity even after the cessation of a train of waves, it becomes necessary to provide means for automatically imparting a slight blow or jar to the tube in order to restore its receptiveness after each and every signal. Such a device was used by Lodge and is known as a "tapper." It is generally in the form of an electric trembling mechanism, such as an electric bell, operated by a local battery when thrown into the circuit by a Morse relay—the latter acting in response to the increase of current when the coherer acts.

The coherer used by Marconi at this time was his own special modification of the Branly-Lodge type. It consisted of a glass tube

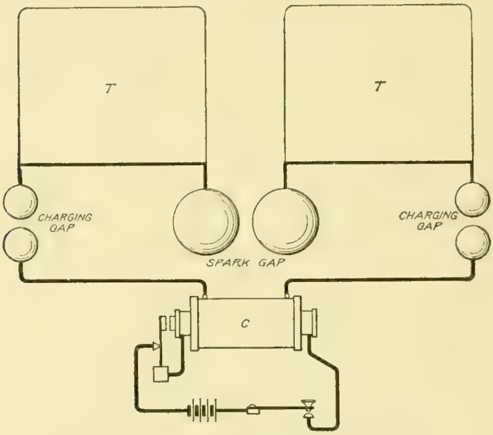


Fig. 14. Marconi "Capacity Areas"

about 4 centimeters long and 2.5 millimeters in diameter, into which were tightly fitted two silver terminals separated to a distance of one millimeter, this space being filled with a powdered mixture of 96 parts nickel to 4 parts silver, worked up with a trace of mercury. The tube was exhausted of air and hermetically sealed. To the terminals of this coherer were connected two resonance plates, or strips of copper, whose dimensions were such as to bring the system into resonance with the oscillator. Also connected to the terminals of the coherer were two choke coils, whose function was to confine the oscillations to the coherer; and a Morse relay in series with a battery of one cell. Fig. 13 plainly shows the arrangement.

In addition to the above a tapper was provided to decohere the metal filings, and also a signal recorder. The tapper was in the form of a small electric-bell mechanism whose clapper continuously tapped the glass tube as long as the Morse relay completed the circuit in which the tapper was placed. The Morse relay thus acts as a switch by means of which the signal recorder and tapper are operated simultaneously. It might be well to state that the coherer holds its conductivity during the passage of the oscillations even though in vibration from the tapper.

Capacity Areas. A very significant step taken by Marconi at this early period was his employment of "capacity areas" in the circuit of his oscillator, Fig. 14. The essential features of this innovation were as follows: *T* and *T* are metal plates joined to the balls of the oscillator; *C* is the induction coil. The object of this arrangement was to give greater energy to the oscillations, the carrying power of the apparatus being found to increase with the size of the capacity areas, and with the distance of the same from each other. Two similar plates were also attached to the coherer at the receiving station. Though this arrangement of capacity areas was soon abandoned, it marks, nevertheless, the inception of an idea which developed, as we shall see, into one of the most important features of modern aërial telegraphy, namely, the antenna.

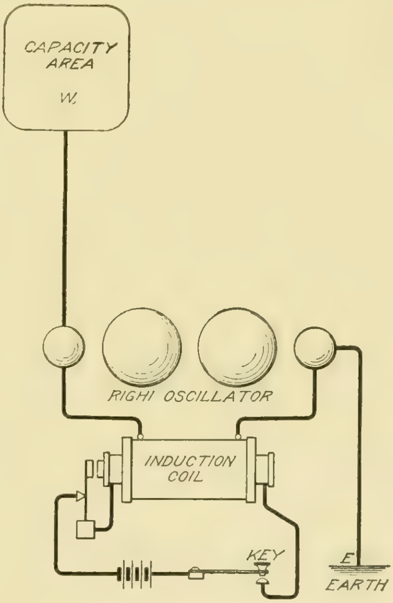


Fig. 15. Diagram Showing the Earthed Oscillator

Development of the Antennae. Endeavoring to increase the effectiveness of his capacity areas by enlarging them and separating them as much as possible, Marconi conceived the idea of utilizing the earth for one of the plates, and of raising the remaining plate to a considerable height in order to increase the distance between them.

The arrangement, Fig. 15, then took on the following aspect: coil and oscillator are of standard type; *E* is the earth connection; and *W* the elevated plate. The higher the capacity area *W* is situated, the greater the distance to which communication can be carried; so it will be seen that the capacity area might with great advantage be attached to a kite, or captive balloon. The latter were, indeed, employed by Marconi and with very good effect. Corresponding changes were made at the receiving station also, by employing a similar arrangement of capacity area, shown in Fig. 16.

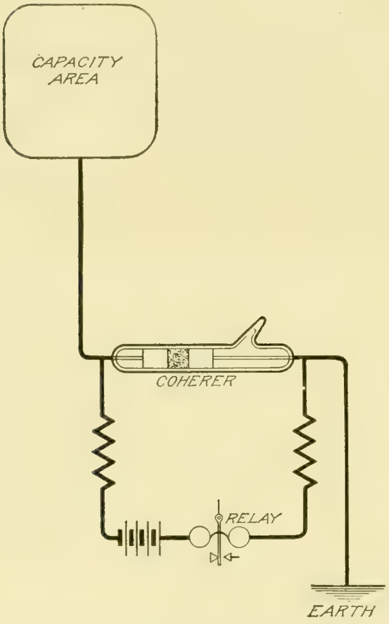


Fig. 16. Earthed Receiving Circuit

Later Marconi became convinced that the effectiveness of his aërial line was due not to the capacity at the end of the wire, but to the length of the wire itself; consequently he abandoned the capacity area altogether and held simply to the form of vertical wires attached to poles or kites, or even to high buildings or towers. These were called antennae, or aërials. The antenna consisting of a single wire later developed into the multiple antenna of several wires, each additional wire adding to the capacity of the system. The antennae of many large stations are formidable structures of great complexity, as the picture of the South Wellfleet station, Fig. 17, will indicate.

Inductive Receiving Antennae. Another of Marconi's early and important modifications was the introduction of inductive antennae into the receiver arrangement. The antenna was cut out of direct conductive connection with the coherer circuit and allowed to act on the latter only by induction through the agency of an oscillation transformer called in common parlance a *jigger*, the theory of which cannot be fully discussed here. Mention will be made, however, of the fact that such a transformer properly designed in regard to the wave-length used not only steps up the voltage so as to increase its effect on the coherer, but also enables the coherer to be placed at a nodal point of the secondary oscillations. As this form of detector is of the potentially operated variety, the practical importance of the modification is apparent. A coherer placed in series between the antennae and ground, as in former arrangements, is poorly located, as at the base of an aërial the potential is a minimum and the current a maximum. Marconi increased the distance over which it was possible to signal nearly ten times by the employment of this simple device. His patents on this improvement bear the dates of 1898 and 1899. Fig. 18 shows a diagrammatic cross-section of the jigger, the zigzag lines representing the successive layers of the windings wound in such a manner that the inner layers have the greatest num-

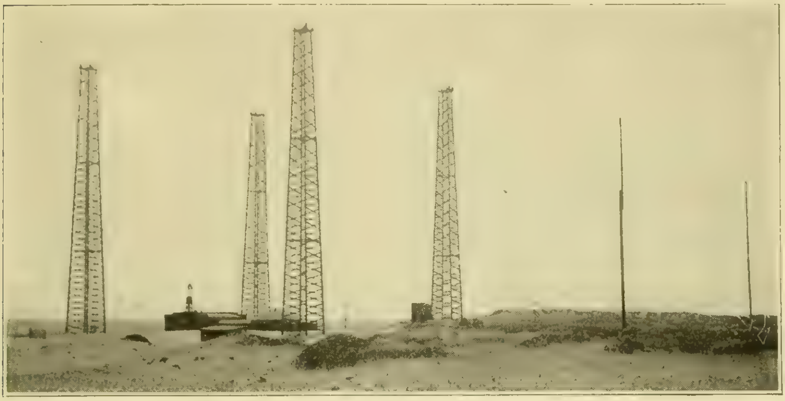


Fig. 17. South Wellfleet Wireless Station

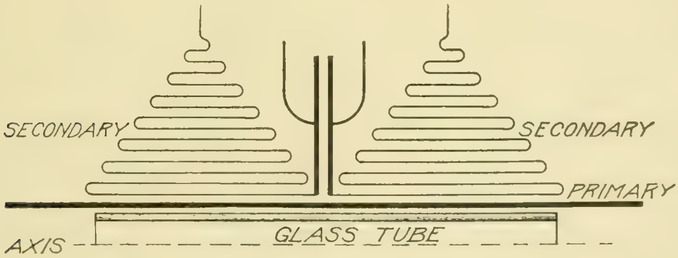


Fig. 18. Diagram of Oscillation Transformer Winding

ber of turns, the primary having about 100 and the secondary about 1,000 turns. Fig. 19 shows the receiver-circuit with the jigger embodied therein. It will be noticed that the local-battery circuits are the same as used before, but the jigger necessitates a slight modification in the location of the coherer. A condenser is connected to the inner terminals of the secondary, the outer terminals of which are connected to the coherer. The local battery circuit is also connected to the inner ends of the secondary and across the condenser.

Inductive Transmitting Antennae. It has already been shown that the early capacity areas had given place to the extended wire raised to a great height; and it soon became evident that transmission could be further facilitated by devising a more persistent oscillator than that which was employed with the directly connected aërial. It was possible to store a fair amount of energy in the old type of aërial, but the direct connection entailed the disadvantage of permitting the apparatus to radiate its entire amount of energy almost instantly instead of radiating such energy in the form of a more continuous train. This was not a quality tending to make for a clearly defined resonance between the sending and receiving circuits, and means were sought to accomplish a more persistent, or less damped, series of oscillations. The early form of open-circuit oscillator, therefore, gave place to what is known as the Marconi-Braun type of closed oscillating circuit which, while not so powerful a radiator, was a very much more persistent one. The method was due to Prof. Braun, but in a modified form was first used by Marconi. The diagram of Fig. 20 makes clear the fundamental idea, an idea which has proven to be of great value. Though modified in numberless ways by subsequent inventors, the broad idea of associating the aërial with a closed oscillating circuit has become almost universal.

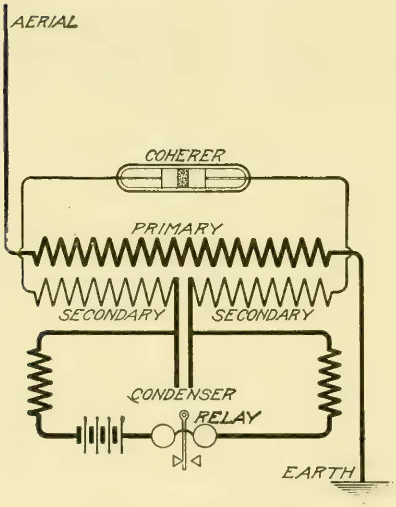


Fig. 19. Marconi Receiver-Circuit with Jigger

The transformer used for this purpose is very different from the ordinary induction coil or alternating-current transformer employed in connection with low voltages and low frequencies. It will be fully described later under the head of oscillation transformers; for the present it is sufficient to say that it forms an inductive couple between the two oscillatory circuits, the closed circuit being but a means of charging the open circuit of the antennae. The antennae circuit, having a certain amount of capacity and inductance depending on its design and position, possesses a natural time-period of its own; so in order to induce in such a circuit oscillations of a maximum amplitude, the primary circuit associated therewith must have the same natural time-period. In other words, resonance must be established; two circuits, as before mentioned, being in resonance when the product of capacity and inductance is the same for both. The Marconi-Braun method of charging the aërial permits of the employment of very large capacities, with proportionally larger energy-storing ability and smaller inductances in the primary circuit, so that the product of these two factors can be made to equal the product of the corresponding factors in the antenna circuit. The efficiency of the transformer thus very largely depends on the establishment of syntony between the closed oscillatory circuit forming the primary and the open oscillatory circuit forming the secondary.

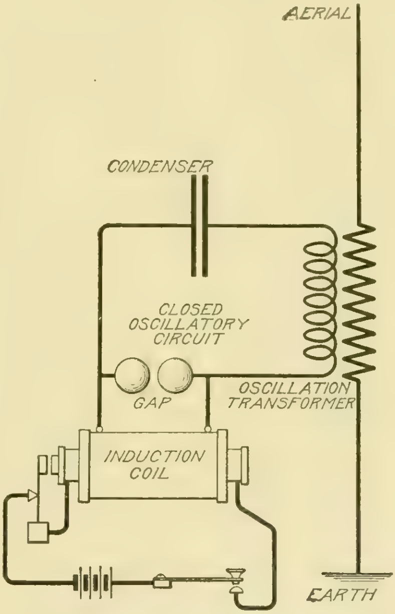


Fig 20 Marconi-Braun Inductive Transmitting Antennae

Another method of associating the radiating aërial with a closed oscillatory circuit, possessing many of the advantages of the Marconi-Braun inductive couple, is shown in Fig. 21, and is known as the direct-coupling method. An inductance of several turns of wire is, in effect, introduced in series with the aërial and the ground. A certain portion of the inductive turns is included in a closed oscillatory circuit composed of a condenser and spark gap shunted around the said portion. When the closed energy-storing oscillatory circuit and the open radiating circuit of the aërial are adjusted to the same periodicity the scheme becomes effective. The method of direct coupling has been subjected to many changes at the hands of inventors, in some cases becoming almost unrecognizable, but upon analysis the fundamental idea shows through. It is to be noted that with both the direct and inductively coupled systems, syntony between the open and closed circuits is essential.

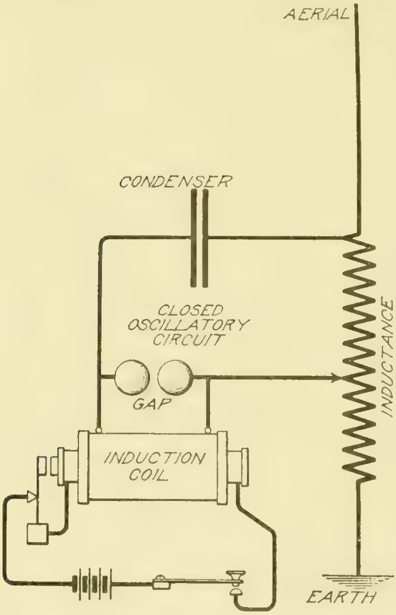


Fig. 21. "Direct-Coupled" Inductive Antennae

Both of the foregoing arrangements allow the possibility of creating in the aërial far greater charging electromotive forces which, in properly proportioned antennae, increase toward the top where they may reach a value equivalent to hundreds of thousands of volts in the larger installations. Hence, with the adoption of this form of transmitting arrangement, it became possible to radiate a series of well-sustained oscillations of much greater energy than ever before, thus still farther extending the distance to which communication could be carried. This improvement may be said to be one of the greatest advances in the history of radiotelegraphy.

Propagation of Waves from a Grounded Oscillator. The theory of the propagation of electric waves from a Hertz oscillator before given, assumed a perfectly symmetrical isolated oscillator suspended in space. The employment of the grounded oscillator in the form of an earthed aërial now exclusively used in radiotelegraphy necessitates a modification of the above theory in order to meet the problems arising under the charged conditions. The new arrangement was, in effect, the substitution of the earth for one of the capacity areas of a Hertz radiator, and the extension of the companion area into a vertical wire possessing capacity with regard to the earth from which it is separated by an air gap. The type of wave radiating from such a system differs in many respects from the form of disturbance emanating from a simple isolated oscillator, and presents theoretical difficulties which cannot as yet be said to be satisfactorily explained. The electric waves from a grounded oscillator apparently follow the curvature of the earth. One of the theories purporting to account for this phenomenon assumes that such waves are not ordinary free electric waves consisting of closed loops of electric strain, but on the contrary consist of half loops traveling over the surface of our globe with their ends remaining always in contact with the surface. This view is supported, it would seem, by the electronic theory of electricity. It is roughly represented in Fig. 22. The detached semi-loops of strain are shown by the lighter lines, and the simple grounded oscillator by the heavier. A wave-length would be represented on the horizontal line by the distance included between any two positions thereon where the direction and intensity of strain (shown respectively by the arrows and the proximity of the lines) is identical. This is the *sliding-wave theory,* said to have

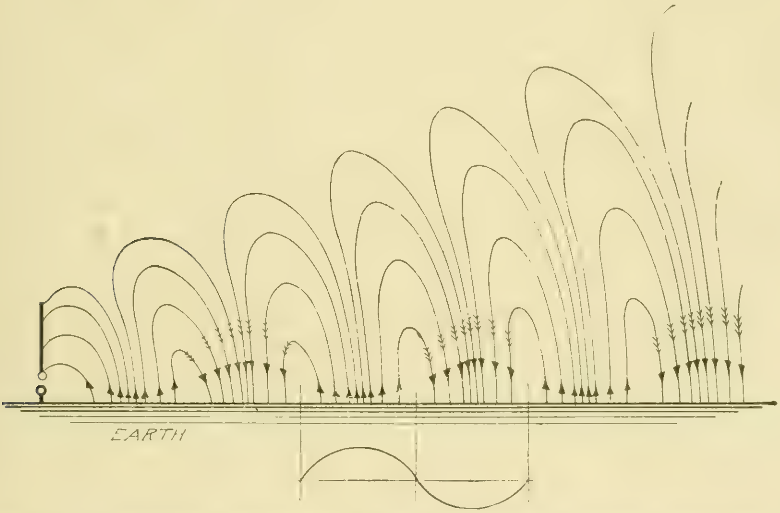


Fig. 22. Diagrammatic Representation of the Sliding-Wave Theory of Propagation

been first promulgated by J. E. Taylor. Other theories have been advanced to account for the wave-transmission following the curvature of the earth, one such assuming that the waves are radiated in a straight line but reflected back from a semi-conductive envelope formed by the upper strata of the earth's atmosphere.

Selective Signaling. The problem of directing a message to its proper destination was felt by early investigators to be of vital importance, if radiotelegraphy was ever to be a commercial success. Some method must be discovered to effect selective signaling—else how would it be possible for a plurality of stations to be transmitting at once? The solution of the difficulty was thought to be found in the principle of resonance.

The history of the subject records at a very early date efforts to achieve the desired end by employing definite wave-lengths corresponding to the electrical time-periods of the various stations it was desired to place into communication. Thus among a plurality of active sending stations any number might communicate simultaneously in pairs without interference by arbitrarily assigning a definite frequency, or wave-length, to each pair. Selection by this method assumes that it is possible to "tune" receiving instruments so they will respond to a particular "pitch" and to no other; but as the number of possible non-interfering wave-lengths is limited, it cannot be said that resonance offers an entirely satisfactory solution of the problem.

By the employment of two or more receiving circuits connected to the same aërial, each tuned to a different frequency corresponding to as many different sending stations, the simultaneous reception of two or more messages is theoretically possible. As early as 1900, Marconi achieved some very remarkable results of simultaneous non-interfering communication when he received by the same aërial two messages, one in English and the other in French, which were simultaneously transmitted over a distance of 30 miles.

It was to be expected that the last few years would bring in their train great improvements in this respect as well as in others, so that it may be said today that selective signaling is feasible to a certain extent and that the remaining obstacles will be removed by further developments of the art; but until those advances are made, so that much more can be accomplished with respect to selective signaling than at present, the field of operation for radiotelegraphy will be confined mostly to communication between ships, between ships and shore, and across large bodies of water.

Conclusion. The application of Hertzian waves to the purposes of telegraphy as outlined above, covers what might be called the foundation and early development of the art. Every step taken at this early period was vital and significant. Since then enormous advances have been made; the distances over which it is possible to telegraph have been greatly extended, and the apparatus rendered more sensitive and certain in every way; but these results have been accomplished more by a refinement of detail—the development of more sensitive instruments, and the closer connection between theory and practice—rather than by the application of fundamentally new ideas. The twentieth century ushered in a new and tentative method of telegraphic communication called radiotelegraphy, and the first ten years have witnessed its establishment as one of the permanent adjuncts of civilization.

CHAPTER IV

RADIOTELEGRAPHIC APPARATUS

It is obviously impossible within the scope of the present work to give a detailed description of all the apparatus pertaining to radiotelegraphy. In view thereof it is assumed that the reader is familiar with the ordinary instruments and physical appliances commonly used in electrical work and not in any way peculiar to wireless telegraphy. It is also assumed that the elementary facts of electrical phenomena are known. The descriptions of the apparatus in this chapter will be given without reference to their grouping together in the formation of a complete system, but will be given singly with such theoretical considerations as may seem necessary. The chapter following will be given over to the assembling of apparatus into complete systems under their proper appellations, together with some account of their performance.

Sources of Energy. In any system of radiotelegraphy the prime desideratum is to associate with the aërial a maximum amount of energy available for radiation. It was early recognized that the most obvious way to accomplish this was to increase the capacity of the aërial or to employ condensers associated in various ways in order to store temporarily the electrical energy to be radiated. The main function, therefore, of the source of energy employed in the transmitting station is to properly charge a given capacity. The greater this capacity, the greater the amount of initial energy required. Expediency determines largely the nature of the source of energy, whether derived from storage batteries, a generator, or from power mains. The energy consumption ranges from a few watts up to 50 to 100 kilowatts, so it is evident that the sources of current are subject to a wide range of choice. The trans-Atlantic stations of Marconi at Cape Breton employ generators of 65 horse-power.

Charging Devices. To create the required electrical oscillations in the aërial, it is necessary to have appliances which shall generate the requisite high-potential electromotive forces for charging the aërial and its associated capacity. Such an appliance should create not only a high potential but also an appreciable current. This charging e. m. f. is generally effected by the use of the induction coil or the alternating-current transformer.

Induction Coils. It is not deemed necessary to give an extended discussion of the induction coil, but to call attention to the important modifications to be incorporated therein for use in wireless telegraphy. The purpose for which the coil is employed is to charge a condenser of some form rapidly. The time required for a condenser to attain the same potential as the charging source to which it is connected depends largely upon the resistance of the charging source. In order to secure a small time-constant for the charging circuit, it is highly desirable to have a secondary of as low resistance as possible. The lower the resistance of the secondary, the greater the capacity that can be rapidly charged by a coil of a given number of turns. It must be borne in mind that, in order to charge a condenser to a given potential, current is required. The usual small induction coil is wound with very fine wire on the secondary—No. 36 or finer. It goes without saying that this is not at all suited for use in wireless telegraphy. Considerable data on coils suitable for the use herein considered is available. The core should be composed of well-annealed, Swedish soft iron wire of small diameter—about No. 24—wound with a primary of comparatively few turns of coarse copper wire—about No. 12—double cotton-covered and well insulated from the core. It is not practical to wind the secondary with coarser wire than No. 32 or No. 33 B. & S. gauge. Special attention should be paid to the insulation of the secondary as it is of great importance that this be able to withstand the high impulsive electromotive forces of short duration which occasionally manifest themselves. Late design seems to be in the direction of longer cores—about twice the length of the secondary winding.

Tesla called attention to a fact of importance in connection with induction-coil design, as far back as 1893, viz, that a condition of resonance between the primary and the secondary circuits greatly adds to the efficiency of the device. This has the practical result of greatly decreasing the resistance of the secondary and also the number of turns, with a result that much more current is deliverable from such a coil. In the primary circuit there is usually large capacity and small inductance, while in the secondary there is small capacity and large inductance.

Even with the above added efficiency, induction coils are not as suitable in many respects for commercial radiotelegraphy as alternating-current transformers. The utility of the induction coil is limited by reason of the fact that the details of design are so largely a matter of compromise that it is impracticable to obtain the desired charging current at the required voltage. The efficiency of induction coils is at best but slightly above 50 per cent, and there are reasons for believing it much lower.

The three important adjuncts of the induction coil are the primary condenser, the interrupter, and the signaling key.

Primary Condenser. The principal function of the primary condenser is to absorb the energy that manifests itself at break in the form of an arc, due to the self-induction of the primary circuit. As the secondary e. m. f. is due largely to the suddenness of the rupture in the primary, it is of the utmost importance that this arc be prevented from forming. The primary condenser is, therefore, placed across the break in such a manner as to be short-circuited when the circuit is closed, but at the instant of break it is placed in the circuit and absorbs the energy which would otherwise be dissipated in the formation of an arc, and which would very greatly increase the time of rupture. Fig. 23 indicates the arrangement of the circuit. The best value for the primary condenser is that capacity which will annul to the greatest degree the sparking at the points of the interrupter. Experiments have shown that if the primary be broken with sufficient rapidity, as for instance with a rifle ball, no condenser is needed. A condenser is not needed with a Wehnelt interrupter.

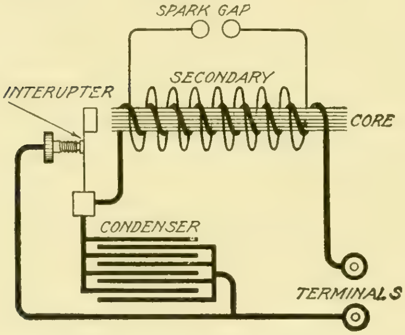


Fig. 23. Diagram of Induction Coil Showing Condenser Circuit

Interrupters. Interrupters perform the sole function of causing a rapid succession of sudden breaks in the primary circuit. The commonest as well as the oldest form of break is known as the *hammer* *break,* probably invented by Neef. Its action is perhaps best shown by referring to the common electric door-bell. An electromagnet, in attracting an armature, causes an interruption of the current energizing the electromagnet, whereupon the armature falls back by reason of its spring tension and again completes the circuit; this energizes the magnet once more, which again attracts the armature, and the whole operation is repeated. The armature is thus kept in continual vibration with consequent interruptions of the current. Fig. 24 shows this device—which is subject to almost endless variation—in a form having as one of its decided advantages the ease with which it is adjusted by simple regulation for different frequencies. Fig. 25 shows another form with the contacts made in small cups of mercury, known as the *Foucault break.* It is obvious that the break can be produced independently of the current in the primary circuit by means of a small electric motor acting on a lever which is made to dip into a cup of mercury, thus completing the circuit any desired number of times per revolution. Such a break is called the *motor break.* The rotary, or turbine, break has been used very successfully on large coils requiring considerable amperage for their operation. The simple hammer break does not operate well with voltages over 16 or 20; therefore, when it becomes necessary to utilize commercial pressures such as 110 and

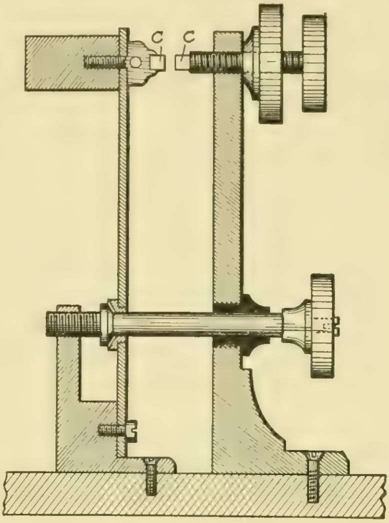


Fig. 24. Neef Hammer Break

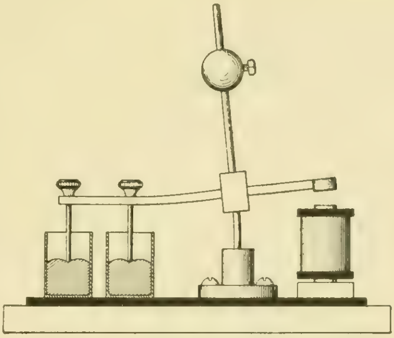


Fig. 25. Foucault Mercury Break

220 volts, some form of mercury turbine interrupter is found to be preferable. One form of this interrupter is shown in Fig. 26.

Dr. Wehnelt of Charlottenburg invented, in 1899, a form of interrupter for use with induction coils, operating on an entirely different principle from those described above. Taking two electrodes of very different size, such as a large lead plate and a small piece of platinum wire projecting from the end of a closely fitting glass tube, and placing them in an electrolyte of dilute sulphuric acid, he discovered that an electrolytic action takes place when the large lead plate is made the negative pole, this action interrupting the current periodically when the device is connected to a source of 40 to 80 volts. Fig. 27 gives an idea of the device, showing one of the many modifications it has undergone in its commercial design. The positive platinum electrode can be seen protruding slightly from the end of the porcelain insulating tube immersed in the liquid, which must be a solution of about one part sulphuric acid to ten parts of

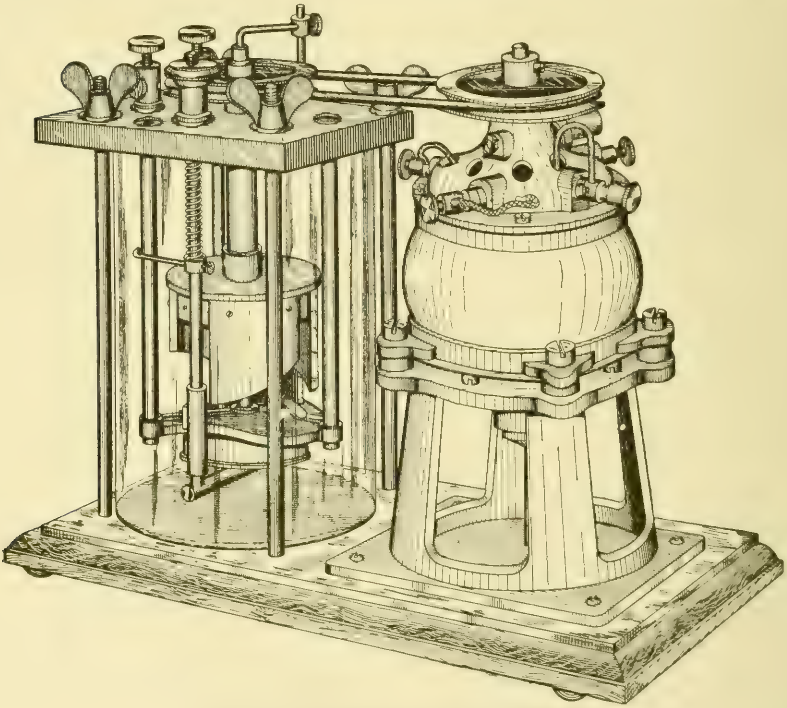
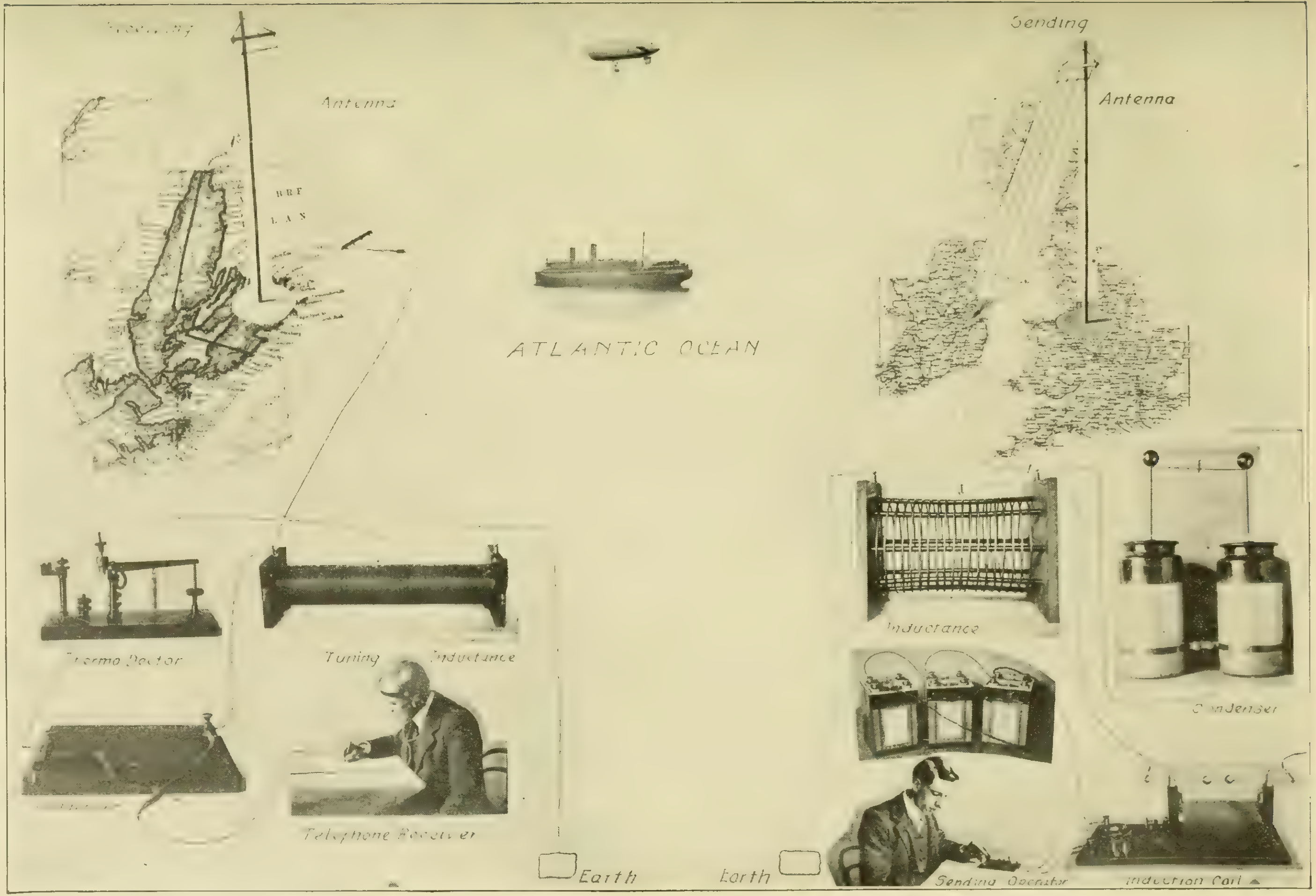


Fig. 26. Mercury Turbine Interrupter



PICTURE DIAGRAM SHOWING IN SIMPLIFIED FORM THE PRINCIPLE AND CIRCUITS OF WIRELESS TELEGRAPHY

water. The cut shows a water-cooling jacket, which is an advantage as the apparatus becomes very warm under continued use. Experiments have shown this device to be capable of producing an intermittency of over 1,800 per second. As mentioned above, no condenser is necessary when operating an induction coil with this form of interrupter. The character of the secondary discharge is somewhat changed by the use of the Wehnelt cell, rendering it more like the alternating arc than the usual disruptive spark. It cannot be said that an entirely satisfactory theory has ever been given for the action of this cell. The Wehnelt interrupter has not been used very commonly in connection with radiotelegraphic work, its greatest field of usefulness being in Röntgen ray work.

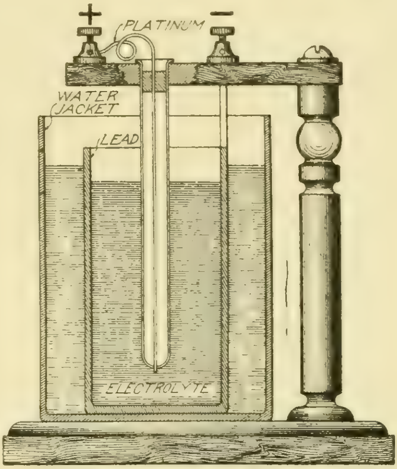


Fig. 27. Wehnelt Interrupter

Keys. In order to transmit messages by means of an arbitrary code consisting of long and short trains of waves representing the Morse alphabet, an adequate means of controlling the torrent of sparks between the electrodes of the spark gap must be employed. The key problem in this form of telegraphy is somewhat more complicated than in the ordinary wire systems, primarily by reason of the fact that a much greater current must be controlled. The common Morse key need not open more than a fraction of an inch, $\frac{1}{64}$ being ample; but it becomes necessary in wireless work to rapidly break currents of several amperes in circuits of considerable inductance, under which conditions the Morse key would not answer at all. The speed of signaling depends largely on the rapidity of the key, a wide movement greatly cutting down the efficiency of the system as a means of communication; therefore, short-range keys must be provided, with some means of annulling the heavy spark on break. Many suggestions have been made and a number of patents taken out purporting to accomplish this end. The magnetic blow-out has proved the most generally useful; though some systems employ a short-circuiting resistance around the break, and others a condenser to absorb the arc. One form of Marconi key simultaneously breaks the primary current and disconnects the aërial from the transmitting apparatus. Many keys are designed to cause the break to take place under oil or other highly insulative substances. Lodge and Muirhead employ an electromagnetically operable key which is actuated by current in a local circuit interrupted by an ordinary Morse key. A common form of such a key, which is of very heavy construction and of extra wide movement, is shown in Fig. 28.

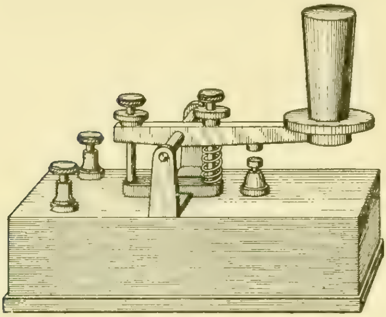


Fig. 28. Long Range Morse Key

Alternating-Current Transformers. In nearly all high-power stations it has been found advantageous, if not absolutely necessary, to discard the induction coil as a means of charging the high capacities used, substituting the alternating-current transformer. This involves the employment of an alternating-current as the initial source of power. Transformers designed for this purpose are wound for a high ratio of transformation, generally for a secondary voltage of at least 20,000 volts, and often 30,000 to 50,000. A difficulty experienced with the use of the transformer is the liability of forming an alternating arc between the balls of the gap in place of the proper oscillatory spark. The practical short-circuiting of the transformer by this action causes a great rush of current through the primary, which, if it has not been guarded against, is liable to cause great havoc with the generator, blowing out the fuses and possibly working other damage more serious. When the capacity of the condenser is of the exact value to take up in the form of a charge nearly the entire energy of each half-wave of the periodic current, no alternating arc will arise and the discharge across the gap will be due entirely to

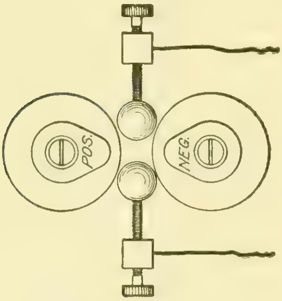


Fig. 29. Tesla Magnetic Blow-out

the condenser, in which case no external means for extinguishing the arc are necessary; but this relation is very hard to effect permanently, so that numerous plans have been devised to prevent the formation of this arc. The one due to Nikola Tesla, which has undoubtedly proved to be the best, utilizes a strong electromagnet so that its lines of force pass transversely between the spark gap. This arrangement is called a *magnetic blow-out* Fig. 29 shows the scheme. Elihu Thomson achieves the same end by directing a strong blast of air on the gap from a nozzle. This permits the oscillatory spark to form at the proper time, but completely extinguishes the alternating arc, or rather prevents its formation. The noise incident to the operation of a large transformer producing a heavy oscillatory spark is deafening and some precaution must be taken to protect the ears of an attendant if the gap is not enclosed. The light from such a spark is also very hard on the eyes.

Oscillation Transformers. Transformers designed for high-frequency, high-potential, oscillatory currents are in many respects different from the transformers suitable for use on low-pressure, low-frequency, electric-light mains. The most striking difference is the absence of an iron core and the small number of turns of wire employed. The transformer used by Marconi with the Marconi-Braun type of closed oscillator was constructed as follows: The primary consisted of but one turn on a stranded conductor of low resistance with a secondary of thinner wire laid over the primary in about ten turns. The coils were immersed in highly insulating oil. In commercial practice oscillation transformers are of various design. It is of the utmost importance that transformers of this character be specially well insulated, particularly when the primary and the secondary are in close inductive relation. The use of oil in this connection is the common practice. Late forms of oscillation transformers are made in such a manner that the distance between the primary and the secondary may be varied, thus alternating their inductive relation, a so-called "loose couple" being produced by separating the two components.

Condensers. The condensers employed in radiotelegraphy, as in other departments of electro-technics, are chosen with regard to the voltages to which they are to be subjected. The capacity used in connection with receiving circuits requiring no high insulating properties generally takes the form of paper or mica condenser supplemented by a variable-capacity condenser consisting of a number of fixed metallic plates interspaced in air between an equal number of moveable plates, whereby the effective capacity areas of the plates may be varied within wide limits.

In the transmitting circuit where the condenser is employed to temporarily store the energy preparatory to the sending of a signal, a form of condenser must be used which will withstand the electrostatic strain of a very high potential. This necessitates the use of glass, mica, or oil, as experience has proved these materials to be almost the only dielectrics practicable for the purpose, glass being, all things considered, the best of all. The higher the voltage, the greater the thickness of glass needed; and as the storing power of a condenser varies directly with the square of the potential to which it is charged, it is evident that there exists a definite relation between the dielectric strength of the medium (glass) and the volume per unit of energy which it is desired to store. This is equivalent to saying that a great amount of energy could be stored in a very small condenser if the dielectric could stand an exceedingly high potential. Hence, the object to be attained in the designing of condensers for radiotelegraphy is a maximum energy-storing ability with a minimum of cost, size, and weight of glass. In practice it is better to use a good grade of glass free from lead and other impurities. Oil condensers are sometimes used, constructed of sheets of brass or zinc, and immersed in "transformer oil." Adjustable condensers, made as shown in Fig. 30, are often used for purposes of tuning; their capacity may be varied by withdrawing the plates, thereby reducing the effective area. Braun employed small condensers made of test-tubes covered with tin-foil inside and out for short-distance low-power stations.

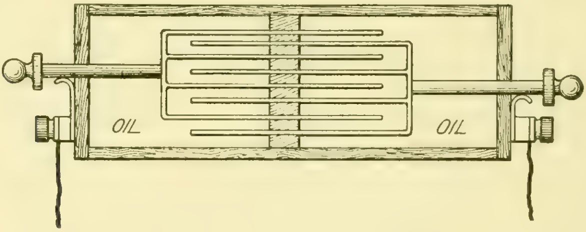


Fig. 30. Adjustable Condenser

Quart or gallon Leyden jars are often employed, lending themselves very well to the requirements.

Tuning Coils. In order to facilitate the tuning, or syntonizing, of the oscillatory circuits included in a system of radiotelegraphy, some apparatus for varying the electrical dimensions of such a circuit is usually employed. These tuning devices consist simply of a variable inductance, or of an adjustable condenser to vary the capacity, or of both embodied in a single piece of apparatus. As the inductance factor lends itself more readily to a simple method of variation, numerous forms of adjustable inductance coils have been devised, the design of which depends upon the circuit they are to be employed with.

Tuning coils for use with the transmitting side of a station are characterized by a comparatively few turns of very heavy wire or metal ribbon wound spirally on an insulated drum or ebonite cylinder. Connection is made at any point on the spiral conductor either by means of flexible connecting cords provided with metallic clips, or by the use of a sliding connection so arranged as to permit of any desired length of the inductive conductor being included in the circuit. Many systems utilize the space within the turns of inductive resistance for the placing of the condensers, thus greatly economizing the room otherwise required for these two portions of the apparatus.

As the receiving circuits usually possess much less capacity than the transmitting circuits, the tuning coils designed for connection therewith have a much larger number of turns. Such coils are generally constructed with several hundred turns of rather fine wire wound on a large bobbin having two sliding contacts so arranged as to include between them any desired number of turns. These coils are made in a great variety of ways.

Spark Gaps. An important element of the transmitting station is the gap, across which the stream of sparks takes place. In a previous chapter attention has been called to the resonator of Hertz and to the metallic balls between which he produced his oscillatory spark. In his book on "Electric Waves" published in English in 1894, he advises that these balls be highly polished. For the small amount of energy used by Hertz this was no doubt advantageous, particularly in the production of short waves; but with the further development of the art it became evident that it was impossible to maintain such surfaces when employing sparks of great volume. The essen tial condition to be fulfilled is that the discharging surfaces shall maintain a permanent condition and not be burned away and pitted by the rapidly recurring heat of the spark. With the utilization of radiators of high power, and with the employment of transformers capable of charging large capacities, the need of a means for maintaining a constant condition of the spark gap became imperative. Special appliances were devised to prevent the pitting of the balls and their consequent destruction.

Marconi early adopted the Righi oscillator plan of placing the balls in a chamber of oil, or other highly insulative medium, thereby excluding the oxygen of the air from the balls and preventing oxidization. He soon found, however, that the insulating fluid was rapidly decomposed under the influence of the more powerful discharges and abandoned the idea in favor of a "dry" ball system.

Numerous inventors have contrived many so-called multiple-ball exciters, among whom is J. S. Stone, whose oscillator is shown in Fig. 31. R. A. Fessenden has conducted numerous experiments which seem to indicate that there is great advantage to be gained by causing the spark to take place in a compressed-air chamber. This is explained by the fact that the effective potential between the balls is thereby raised without rendering the spark non-oscillatory. Better radiation is possible also, according to Fessenden, and it is undoubtedly a great improvement in reducing the ear-splitting noise of the customary discharge. Various compressed gases have also been used with varying success.

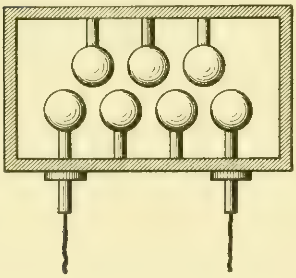


Fig. 31. Multiple-Ball Exciter

Among the various forms of exciter which have more or less successfully fulfilled the requirements, mention must be given to one other fundamental form employed by Marconi. It took advantage of the important fact that though it is exceedingly difficult to create a true alternating arc between two relatively moving surfaces, nevertheless an electric oscillation from a condenser can readily take place even though the movement be exceedingly rapid. Marconi, therefore, devised what is known as the *high-speed disk discharger*, shown in Fig. 32. It would seem that this design of gap possesses many advantages as attested by the extensive employment of it at the trans-Atlantic stations. The illustrations make clear the connections. The apparatus consists of two metallic disks *A* and *B*, revolving at high speed, and a second larger disk at right angles to the axis of the other two and between them, also revolving at high speed. There are thus two gaps where sparks may take place. The closing of the key charges the condensers *C* and *D*, in series between which is connected the condenser *E*, which discharges the energy across either gap between the rapidly revolving terminals. Another modification of this device, shown in Fig. 33, is characterized by the fact that it is designed for use with a direct current. The mechanical construction is similar to that of the form previously described, with the exception that the large disk has a row of metallic studs placed equidistantly around its circumference in such a manner as to greatly shorten the length of the air gap between the two revolving terminals

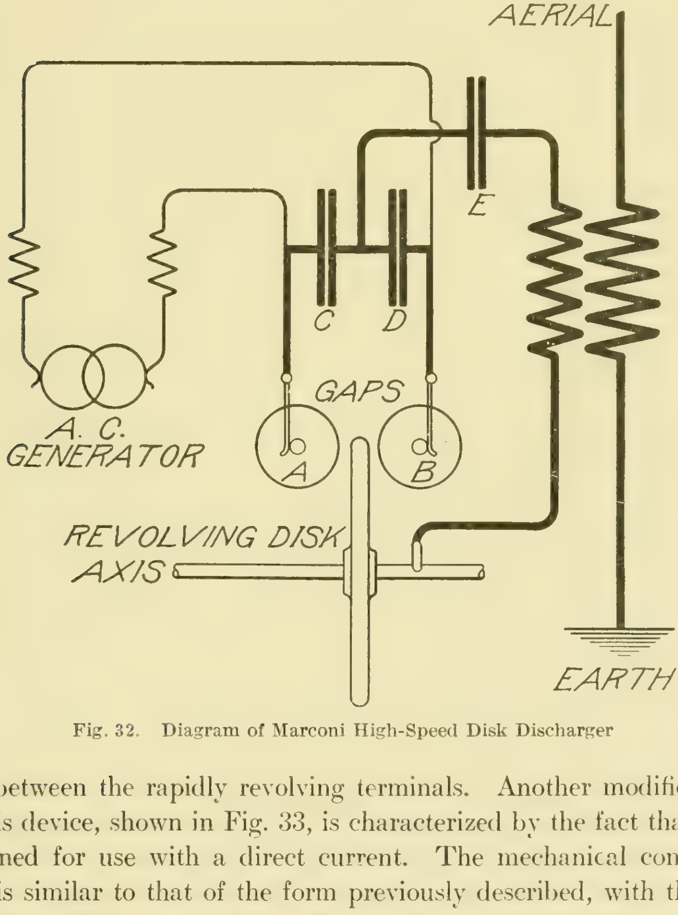


Fig. 32. Diagram of Marconi High-Speed Disk Discharger

when the said studs occupy a position in a line with the plane of their rotation. The office of these studs is to shorten the air gap at predetermined and equal intervals, thus discharging the condensers, which are immediately charged by the direct current. In both forms of the device the arc is prevented by the rapid rotation of the revolving parts. It is claimed that the Marconi dischargers permit of great rapidity of signaling. The last described produces, when run at very high speed, an almost continuous train of oscillations.

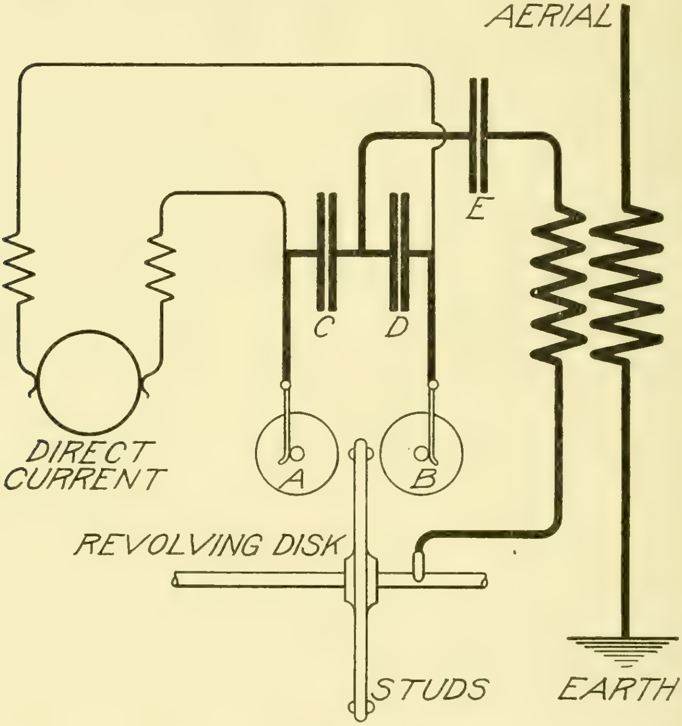


Fig. 33. Disk Discharger for Use with Direct Current

High-Frequency Alternators. It was known at an early date in the history of radiotelegraphy that a much greater efficiency could be achieved if a means were devised for creating a continuous train of undamped oscillations. The Morse dot, which is the minimum signal, was seen to be composed of a considerable number of separate trains of waves, each rapidly damped. Could these "gaps" in the wave train be filled up, the received signal would not only be stronger, but selective signaling would also be greatly facilitated and precise tuning be more easily accomplished. A moment's thought will suffice to convince that a continuous train of undamped oscillations would be the exact equivalent of a continuous alternating current of extremely high frequency; and this opens up the possibility of employing generators which might be connected directly with the aërial, thus doing away with the intermediate condenser and spark gap.

Many attempts have been made to construct generators of sufficiently high frequency, the majority of them having been of the inductor type. An exceedingly small electrical output seems to be the characteristic of all attempts thus far to produce such a machine. Great speed of rotation of the disk armature is required in this type of generator, and as there are limits beyond which it is unsafe to push the rotation, fundamental difficulties arise which have not as yet been surmounted with any degree of commercial success. Fessenden claims to have produced an alternator giving a frequency of 80,000 cycles. The wattage is said to be about 250. The ingenious German inventor, Ernst Ruhmer, has also constructed an alternator of the inductor type having a frequency of 300,000 and an output of but .001 watt; and W. Duddell has succeeded in producing a frequency of 120,000 with somewhat greater power. Until it is possible to greatly increase the output of such machines, their use will be limited to laboratory experiments, or at most to short-distance work in connection with radiotelegraphy. Their development at the present time seems to be in connection with radiotelephony.

The Singing Arc. Much more successful have been the attempts to produce a continuous train of undamped oscillations from a direct current. Elihu Thomson applied, in 1892, for a United States patent on a method intended to effect such a transformation, Fig. 34. A source of direct current is connected to a circuit having a very high inductance, and a spark gap across which is shunted a condenser, and smaller inductance in series. The inventor claims in his patent specifications that the gap, inductance, and capacity can be so adjusted that the condenser is periodically discharged across the gap at frequencies as high as 40,000 per second.

The form that this apparatus has since taken is known by the name of Duddell singing arc, on account of the further developments introduced by him in 1900. Duddell substituted a carbon arc for the gap, and found that such an arrangement produced a clear musical note plainly audible some distance away, the pitch of the note depending on the value of the capacity and the inductance in the oscillatory circuit—the latter is represented by the heavier lines in Fig. 35. The best effects were obtained by the use of solid rods of carbon. The resistance of the inductance in the oscillatory circuit must be low—about 1 ohm. Duddell found it difficult to produce oscillations of any considerable power above a frequency of about 10,000; although other experimenters have succeeded in reaching a frequency of 400,000 with small capacity and little energy.

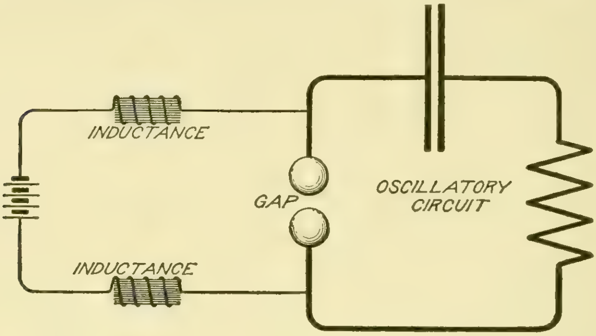


Fig. 34. Thomson Direct-Current Method of Generating Oscillations

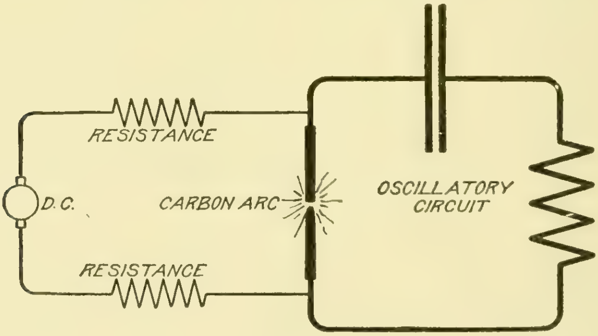


Fig. 35. Duddell Singing Arc

It remained for Valdemar Poulsen of Copenhagen to make the greatest improvement in the direct-current arc method of producing oscillations. Fig. 36 shows Poulsen's arrangement. In the first place, he enclosed the arc in an air-tight chamber filled with coal gas, and used a water-cooled positive electrode with a carbon negative. He also introduced into the chamber the polar projections of two powerful electromagnets in such geometrical relation as to cause the lines of force to pass directly between the electrodes as shown in the diagram. The connecting lines make clear the circuit. The fundamental similarity to Thomson's circuit is apparent. It is possible to produce very powerful undamped oscillations with this apparatus, the frequency of which may, by the proper adjustment of the capacity and the inductance, be made as high as 1,000,000 or more. There is a particular length of arc, called the "active" arc, which gives the best results. Poulsen's device is operable with many other gases besides the one mentioned. The magnets *S* and *N* must be very powerful. 500 volts seems to be a practical voltage for use with this device.

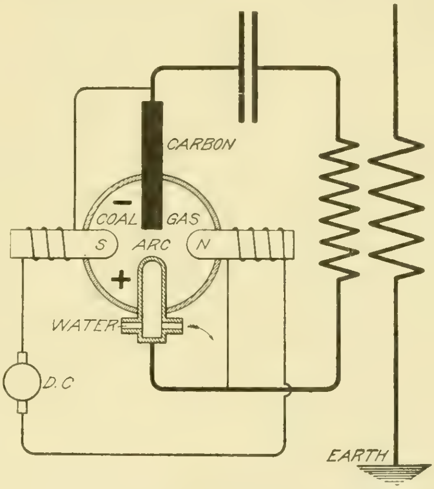


Fig. 36. Poulsen Direct-Current Method of Generating Oscillations

Aërials. The aërials at present used are of many kinds, ranging from the short length of weatherproof wire extending from an upper window to a nail in the chimney, proclaiming the abode of a juvenile experimenter, to those enormous structures taxing the resources of modern engineering in their construction, which achieve trans-Atlantic communication. It was early recognized that the radius of communication was greatly extended by increasing the capacity of the aërial; which fact has led to the employment of multiple-wire antennae. Figs. 37, 38, 39, and 40, show some of the commoner forms, conditions usually determining the choice. It was found by experiment that the capacity of two wires suspended in the air was not twice the capacity of one, nor four wires twice the capacity of two, if such wires were placed near together. The reason, therefore, is apparent why in many of the aërials the individual wires are separated to comparatively great distances.

It is of extreme importance that the upper end of suspended radiator wires should be exceptionally well insulated, and the reason is obvious. Specially designed porcelain or glass insulators are used, having two holes through which the ends of the wires are bound.

Aluminum wire serves excellently for the purpose of antennae when the strain upon it is not too great. Its low tensile strength precludes its use in some cases. A simple manner of suspending a single-wire experimental aërial is shown in Fig. 41. The mast, or short flag-pole, may be lashed to the tallest object available and the wire carried out of perpendicular a sufficient distance to prevent it from hitting the pole. In army field-equipment, kites or captive balloons are often used to elevate the aërial wire, which is carried wound upon a reel. Many aërials are arranged with a tail block on a cross-tree in order that they may be let down from a high mast for inspection purposes. Such aërials are of the cage variety shown in Fig. 38. An idea of the construction of antennae when designed for use in connection with high-power stations may be gained from Fig. 42.

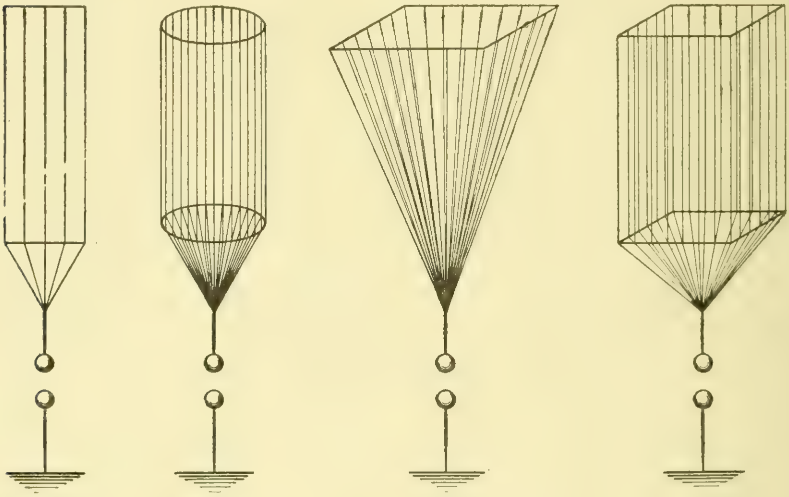


Fig. 37. **Fig. 38.** **Fig. 39.** **Fig. 40.**

Standard Forms of Aërial

Directive Antennae. Many efforts have been made to direct the transmission of radiotelegraphic signals to any desired point or locality, but with indifferent success. Early attempts embodied the use of large reflectors behind the oscillator; but the most encouraging results have been accomplished by the use of what are known as *horizontal antennae,* the subject of a patent granted to Marconi and dated 1904. DeForest has also met with some success along this line. The results obtained by these investigators are not formulated well enough as yet to warrant a description of them here.

Detectors. The subject of the reception of wave-trains and the transformation of their energy into visual or audible signs through the agency of suitable translating devices will now be taken up and described. It is helpful toward a comprehension of this part of the subject to get clearly in mind the primary effect of a train of waves upon a receiving aërial, namely, the creation of an alternating electromotive force. And the prime function of a receiving device is broadly to detect the presence of a high-frequency

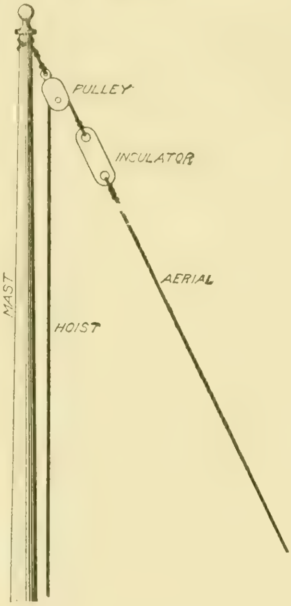


Fig. 41. Single Wire Experimental Aërial

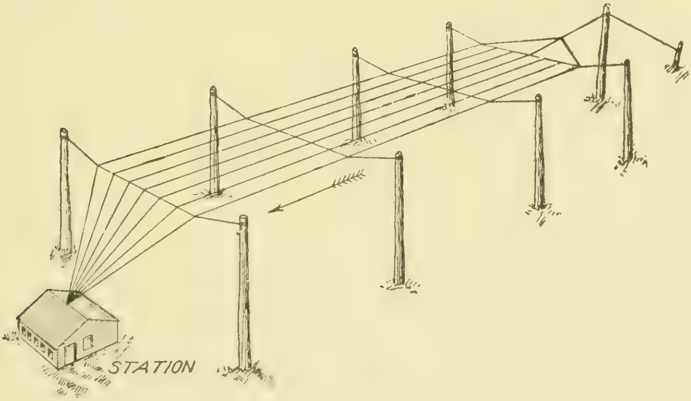


Fig. 42. Antennae Construction for High-Power Station

alternating current of minute value. Volumes could be written on the history of the various forms of receiving devices which have occupied the attention of the various investigators in this interesting field of experiment. In the present instance attention will be called to those forms only which have proved themselves of practical value.

Wave-detecting devices may be classified for convenience according to the physical principle on which they act, such as thermoelectric, magnetic, electrolytic, chemical, photo-electric, physiological, etc. This course will be followed as far as practicable.

Coherers. Coherers work on the principle of imperfect contact and are called self-restoring and non-restoring according as their sensitiveness is automatically reassumed after the passage of a train of waves, or must be superinduced by some external agency. Commercially the coherer has become almost obsolete.

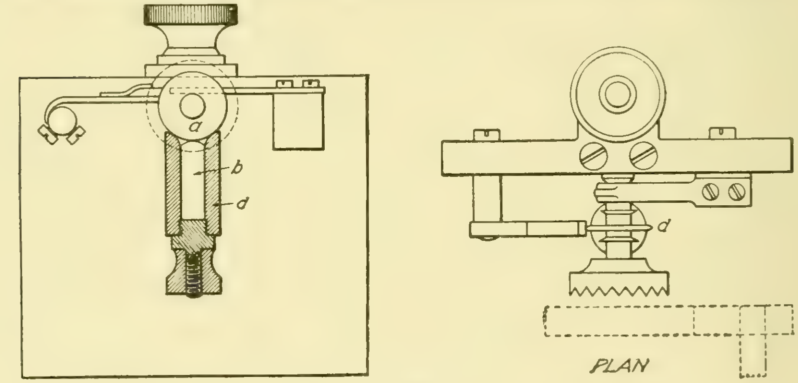


Fig. 43. Lodge-Muirhead Detector

Branly Coherer:—It is unnecessary at this point to give more than passing mention to the Branly coherer, as it has been fully described in a previous chapter. As improved by Lodge and Marconi it performed a very important function in the early days of radiotelegraphy, but has now fallen into disuse.

Lodge-Muirhead Coherer:—An interesting form of contact detector is shown in Fig. 43, devised by Lodge and Muirhead. It consists of a slowly moving steel disk *a* whose sharpened edge is prevented from coming into contact with the small globule of mercury *b* by means of a thin film of oil interposed between the mercury and the steel and contained in the recess *d*. Oscillations passing through the oil cause a breakdown of its high resistance, permitting a translating device to operate by reason of the improved conductivity. Upon cessation of the oscillations, the movement of the disk re-establishes the initial receptivity.

Italian Navy Coherer:—The Marconi Company used with success for a time the so-called "auto-coherer" invented by Signor Castelli, and often referred to as the Italian Navy coherer. The action is entirely automatic. In Fig. 44, i is an iron cylinder separating two globules of mercury; c and c' are of carbon. Cohesion between the mercury globules and electrodes exists only under the stimulus of the oscillations.

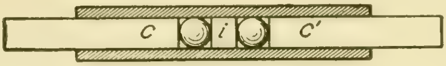


Fig. 44. Castello "Auto-Coherer"

Tantalum-Mercury Coherer:—The tantalum-mercury imperfect-contact detector invented by L. H. Walter is the simplest as well as one of the best of the self-restoring coherers. A small portion of the filament of a tantalum incandescent lamp is connected to a piece of platinum wire for terminal purposes, and the tip of the tantalum is immersed in mercury, which thus forms the other terminal. The whole may be sealed up in a vacuum to avoid oxidization of the mercury. The contact offers very high resistance to a small e. m. f., but falls very low under the influence of the received oscillations. It is rapidly self-restoring. Telephone receivers are often used with this class of detector instead of the Morse relay and recorder, thus allowing the detection of signals from much greater distances owing to the extreme sensitiveness of the Bell instrument to minute differences of current. Such a receiver responds by a buzz to the Morse dash from the distant station.

Valve, or Rectifier, Detectors. One of the difficulties of detecting electric oscillations is the fact that they are of an alternating nature. With the present means at our disposal it cannot be said that we can detect the presence of minute alternating currents with the ease with which we can detect direct currents of equal value. This has led to endeavors to rectify the high-frequency alternations of the received oscillations. Detectors of this type are known as valve, or rectifier, detectors, and one of the simplest means of detecting radiotelegraphic signals is afforded by such devices. To their extreme simplicity is due to a large extent the present number of amateur wireless installations to be seen on all sides. The action of the silicon detector, shown in Fig. 45, is due to the fact that a considerable number of substances in nature possess the property of unilateral conductivity, or the property of conducting electricity freely in only one direction. H. H. C. Dunwoody discovered that carborundum possessed this property to a very marked degree, and would act as a detector if introduced into a receiving circuit in place of a filings coherer. He later observed that no battery was necessary when using a telephone receiver shunted by a small condenser, as shown in Fig. 46. The following substances will all act in place of the carborundum: copper pyrites, iron pyrites, galena, silicon, zinc oxide (perikon), molybdenum sulphide, and titanium oxide. G. W. Pierce has found that the resistance of these substances may be 3,000 times greater in one direction than in the other. The theory of this peculiar action cannot as yet be said to be complete.

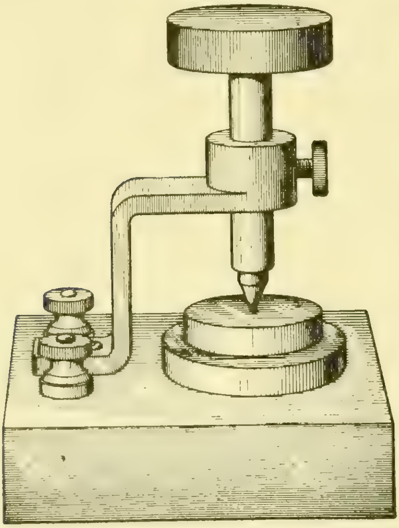
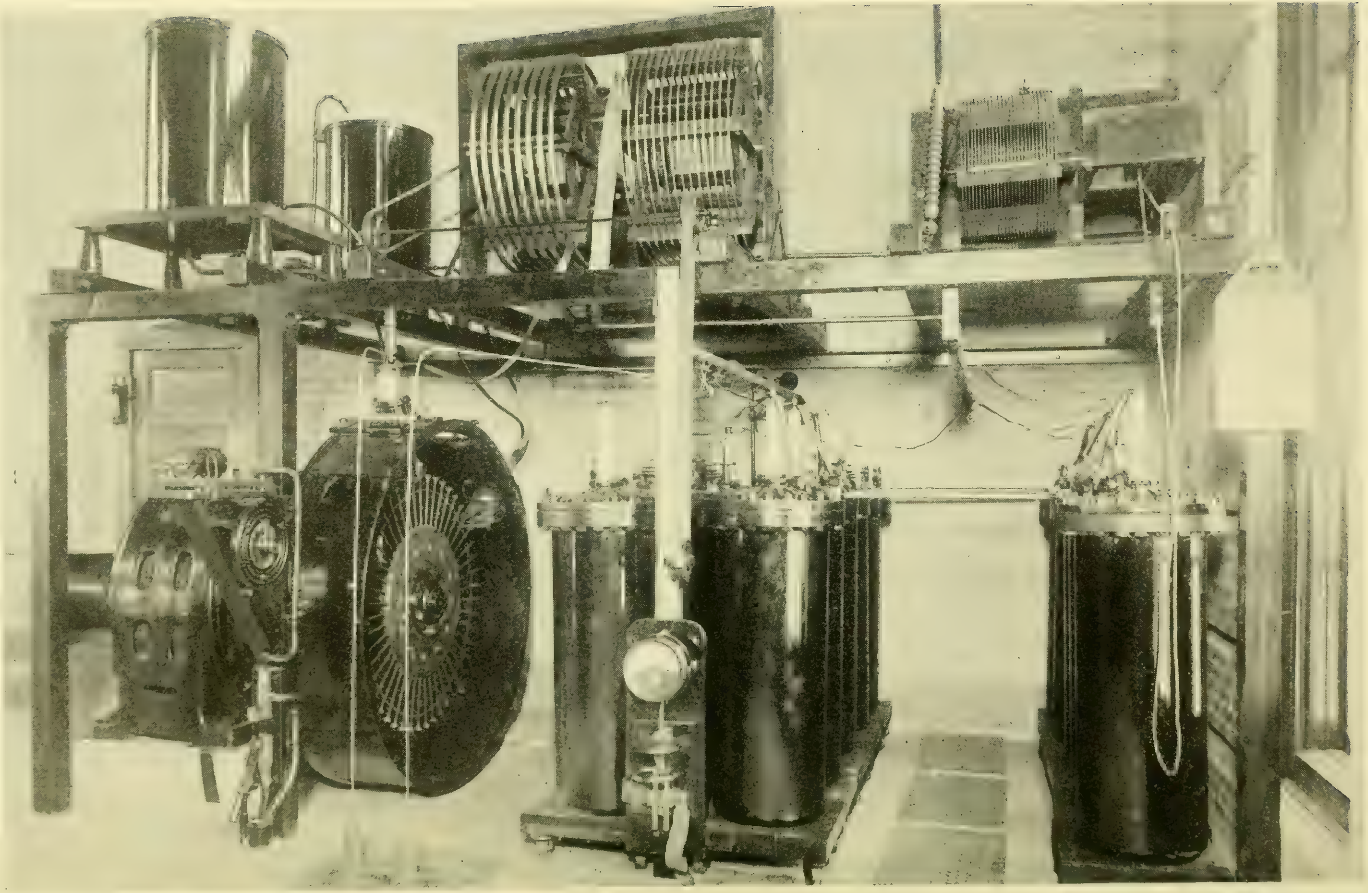


Fig. 45. Silicon Detector

Carborundum, silicon, and perikon seem to be the most satisfactory, particularly silicon, which makes a very sensitive and inexpensive device. Such materials used as detectors of electric waves allow but one-half of each wave to pass, thus giving rise in the telephone to a rapidly pulsating current in one direction to which the telephone can respond. The energy of the oscillations, therefore, directly achieves the audible signal. It has been found, however, that in some cases better results are obtained with a shunted battery cell in the circuit. It is important when using any form of valve detector that excellent connection with the crystal should be maintained at least on one terminal, a deposit of some suitable metal often being employed, thus permitting of a large area of contact. The adjustable contact is preferably pointed and securely held.



TRANSMITTING APPARATUS FOR THE WIRELESS STATION AT RADIO, VIRGINIA

Photograph by G. V. Buck, from Underwood & Underwood, New York

Glow-Lamp Detector:—The glow-lamp detector, invented by Prof. J. A. Fleming, was one of the first valve detectors. The theory of its operation may be understood from the inventor's description and with reference to Fig. 47. "An ordinary incandescent lamp with carbon filament has a metal plate included in the glass bulb, or a metal cylinder *C* placed round the filament, the said plate or cylinder being attached to an independent insulated platinum wire *T* sealed through the glass. When the carbon is rendered incandescent by electric current, the space between the filament and the plate, occupied by a highly rarefied gas, possesses a unilateral conductivity, and negative electricity will pass from the incandescent filament to the plate, but not in the opposite direction. This effect depends upon the well-known fact that carbon in a state of high incandescence liberates electrons or negative ions; that is to say, point charges of negative electricity. These electrons, or corpuscles, are constituents of the chemical atom. Hence a carbon filament in an incandescent lamp is discharging from its surface negative electricity, which may even amount to as much as an ampere or even several amperes per square centimeter. If, then, an incandescent lamp made as described has its filament rendered incandescent by a continuous current, and if another circuit is formed outside the lamp connecting the negative terminal of the filament with the insulated metal plate or cylinder in the bulb, and if oscillations are set up in this circuit, negative electricity will be able to move through this circuit from the filament to the plate inside the bulb, but not in the opposite direction."

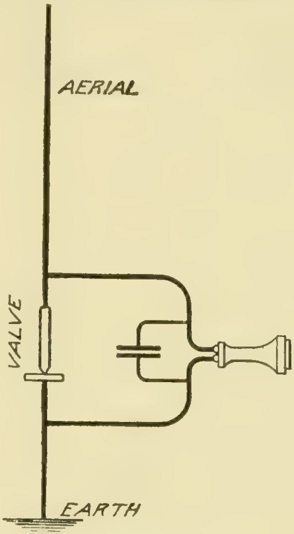


Fig. 46. Diagram of Dunwoody Detector

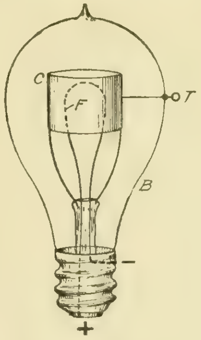


Fig. 47. Fleming Glow-Lamp Detector

It is evident from the foregoing that there are present in the glow-lamp device the essentials of a valve detector. Fig. 48 shows a receiver circuit employed by Marconi making use of the Fleming lamp. Instead of passing the rectified uni-directional impulses directly through the telephone, they are passed around the secondary of a large induction coil in series with a condenser, to the primary of which the telephone receiver is connected. Prof. Fleming is authority for the statement that this arrangement, when suitably adjusted, is "one of the best long-distance receivers for electric waves yet devised."

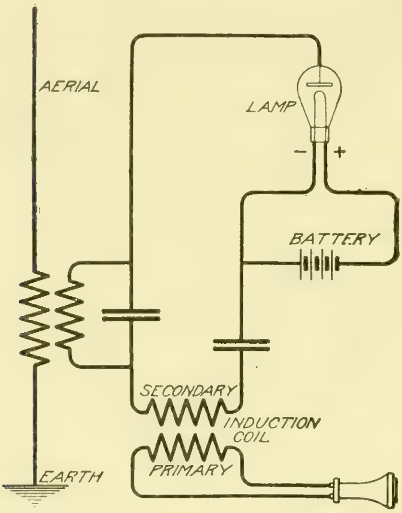


Fig. 48. Marconi Circuit Using Fleming Detector

Audion:—The so-called *audion* of DeForest is a modification of the Fleming detector just described. Fig. 49 shows its connection in a receiving circuit. The lamp used has a low-voltage tantalum filament with two wings, or terminals, sealed in the bulb, as shown. This detector is said to be fairly sensitive, though of short life.

Magnetic Detectors. During the summer of 1902, Marconi was successful in receiving signals sent out from Poldhu on the coast of Cornwall to Flace Bay, Nova Scotia, by means of a remarkably ingenious magnetic receiving device invented by himself and called a *magnetic detector*. Since that time many devices have been patented depending for their operation upon the magnetic effects of the electric oscillations. There has been much discussion relative to the action involved in the Marconi device as well as in other modifications based on the magnetic phenomena

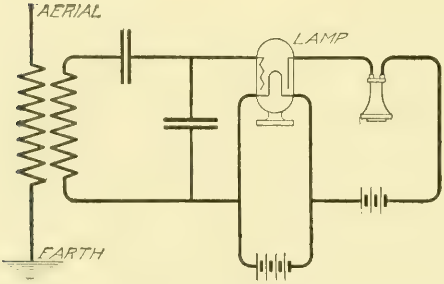


Fig. 49. Receiving Circuit with Audion Detector

associated with oscillatory currents. The explanation advanced by Marconi himself will, therefore, be given here, which in substance is as follows, reference being made to Fig. 50.

The aërial and ground are connected to a few turns of rather heavy wire wound upon a glass tube *T* over which, but insulated from it, is another coil inductively related to the first and connected to the terminals of a telephone receiver. Two strong permanent magnets are placed with like poles together, as indicated. *P* and *P′* are two pulleys carrying on their periphery an endless belt composed of several fine wires of about No. 36 gauge, which are made to pass continually through the axis of the coils by a train of gears not shown. Owing to the hysteresis of the material of the band it tends to retain its magnetism for a short period after it has passed out of the strongest part of the field; but if a train of waves from the aërial is passed through the primary coil to the ground, the effect is to annul the hysteresis and thereby to hasten the demagnetization of the iron wire. This action results in a variation of the flux in the secondary winding, thus inducing electromotive forces in the secondary coil, which make themselves audible in the telephone as a series of sharp ticks. This is said to be one of the most sensitive devices ever made.

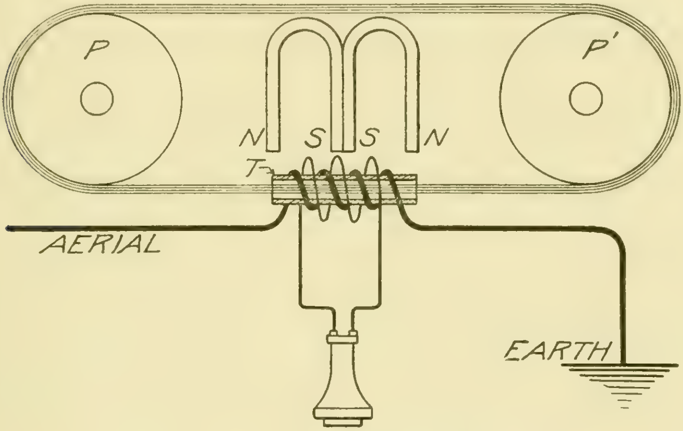


Fig. 50. Diagram of Marconi Magnetic Detector

A diagrammatic drawing of a magnetic detector, invented by H. Shoemaker, which very closely resembles the early embodiment of the Marconi apparatus is shown in Fig. 51. There have been many variations of the magnetic detector but space will not permit of a description of less important forms.

Thermo-electric Detectors. Comprehended under the head of thermo-electric detectors are those instruments which depend for their action on the heating effects of the oscillatory currents. These detectors are especially useful in making quantitative measurements of the amount of energy received under a given condition, and indeed find their greatest utility therein. Fessenden has given great care to his investigations of this form of detector with the result that his so-called "barreter" shown in Fig. 52 is of the same order of sensitiveness as the coherer. It consists of a short piece of exquisitely fine platinum wire connected to suitable terminal wires and the whole enclosed in a vacuum bulb. The temperature rises rapidly under the action of the oscillations, causing an increase in resistance which is indicated by a Wheatstone bridge, in the circuit of which the detector is connected as one of the arms. Attempts have been made to apply the phenomena of the *thermo couple* in this connection, but with only qualified success. It would seem for many reasons that thermo-electrical detectors will not be able to compete with other forms in long-distance work.

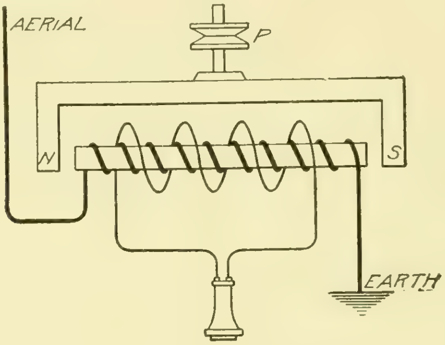


Fig. 51. Shoemaker Magnetic Detector

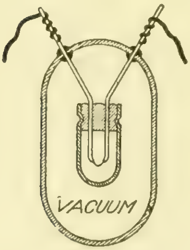


Fig. 52. Fessenden Barreter

Electrolytic Detectors. It remains to take up the class of detectors known as *electrolytic.* DeForest's name is associated with this variety of receiving device, as it was first extensively used by him in a form invented by himself. It consists of a glass tube $\frac{1}{8}$ inch in diameter enclosing conductor plugs after the manner of the Branly coherer. In the interspace is placed a paste composed of rather coarse filings worked up with an equal quantity of oxide of lead in glycerine or vaseline with a trace of water or alcohol. Its resistance increases during the passage of the wave train.

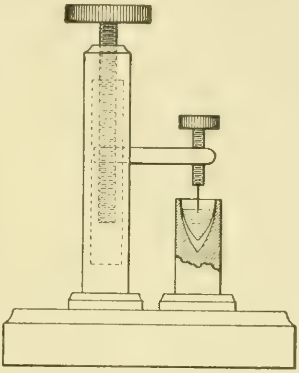


Fig. 53. Liquid Barreter

Fessenden Liquid Barreter:—The most sensitive and practical electrolytic detector is the liquid barreter invented by Fessenden, Fig. 53. It consists essentially of a small containing vessel filled with nitric acid into which projects a platinum wire electrode, which is of extremely small diameter. The apparent resistance of the cell is greatly reduced by the oscillations. The exact nature of the action is not agreed upon by investigators. It was with a refined form of this detector that trans-Atlantic signals were first received from Scotland by the National Electric Company at Brant Rock, Massachusetts.

Hozier-Brown Detector:—The Hozier-Brown system of wireless telegraphy employs a detector classified by some as depending on imperfect contact, but by others as being electrolytic in its action. It consists of a small portion of peroxide of lead held between terminals of lead and platinum, Fig. 54. The lead terminal is much smaller than the other, being a blunt point rendered adjustable by a knurled screw. A two-volt accumulator connected in series gives the best results, according to the inventor.

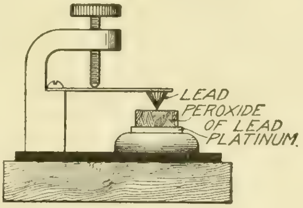


Fig. 54. Hozier-Brown Detector

Electrodynamic Detectors. Mention might be given in passing to the electrodynamic detector devised by Fessenden, although it has never been used extensively. It is designed to operate on the principle that a metallic disk, suspended in a circular coil through which an alternating current is flowing, and at an angle of 45 degrees to the plane of winding of the coil, tends to turn so as to take up a position at right angles to the plane of the coil. This was a fact discovered independently by Elihu Thomson and J. A. Fleming. Fessenden used an extremely light disk hung by a quartz fiber, and he succeeded in obtaining marked deflections of a beam of light reflected from a small mirror fastened to the disk. This device, like the thermo-detector, has been of great service in making quantitative measurements of oscillatory currents.

Auxiliary Apparatus. It would be beyond the scope of the present work to give an extended discussion of the various small devices used in connection with the local receiving circuits, as many of the instruments are not in any way peculiar to radiotelegraphy, being the common adjuncts of wire telegraphy. Mention will only be given to a few points of importance wherein such appliances differ from those commonly employed.

The relay supplied by makers of telegraphic instruments is usually wound with an insufficient number of turns to be efficiently used in connection with a coherer and local battery as a means of actuating a Morse recorder. Rewinding is, therefore, often resorted to. Polarized relays are found to be the best suited to this class of work and should be wound to a very high resistance in connection with all potentially operable detectors. No. 40 wire is often employed.

Sparking at the contacts of the relay is often prevented by the employment of four or five so-called "polarized" cells shunted across the contacts. They are made by inserting a pair of platinum wires through the cover of a small containing vessel partly filled with dilute sulphuric acid, allowing the solution to cover the ends of the electrodes thus formed.

The telephone receivers for use with many forms of detector are much more efficient if wound to a higher resistance than is necessary in the common commercial instrument. Receivers are manufactured in a great variety of forms, only differing from one another in some slight structural modification. The kind known as *operator's double-head receivers* of the watch-case design wound to a resistance of about 500 or 1,000 ohms are well adapted to the requirements of radiotelegraphy.

Dry cells developing an electromotive force, when fresh, of about 1.5 volts are generally used in the local recorder and tapper circuits. One such cell is frequently used in the relay and the coherer circuit.

Measuring Instruments. Perhaps in no department of electrotechnics are the quantitative values of the electrical measurements of more vital importance than in the science of radiotelegraphy. A well-equipped station, therefore, possesses efficient instruments for the measurement of the various electrical factors involved. Besides the common appliances of this nature, such as the voltmeter, ammeter, Wheatstone bridge, etc., it is highly advisable to have the requisite means for making accurate determinations of capacity and inductance. Wave-lengths can be measured by wave-meters, or *cymometers.* These devices are now on the market and are of great utility in a wireless station.

CHAPTER V

SYSTEMS OF RADIOTELEGRAPHY

The history of radiotelegraphy repeats once more the old story that is so often connected with great inventions. The world being possessed of a new scientific principle, many minds in many parts of the world are simultaneously bent upon its practical application, with the result that the fundamental principle finds embodiment in various methods of accomplishing a similar purpose. The startling nature of the discovery of electric waves was bound to give rise to unprecedented activity in the field of experimental investigation; and such experiments as were particularly successful were bound to prompt investigators to seek patent protection on their modifications; and this in turn gave rise to numberless "systems" of radiotelegraphy.

A voluminous list of names could be given of those who have contributed to the advancement of radiotelegraphy in regard to both theory and practice. Among the best-known American investigators are Fessenden, DeForest, Clark, Stone, and Massie. Each of these men has devised a system which bears his name. In England the work has been carried on by men of such unqualified distinction as Lodge, Alexander Muirhead, Fleming, Thomson, and Rutherford. Slaby, Arco, and Braun are the names best known in Germany. The French are represented by Ducretet, Branly, Rochefort, and Tissot, besides other men of lesser fame. We have seen how largely Italy has contributed to the subject; besides Marconi and Righi, mention should be made of Solari, Castelli, and Tommasina. Baviera in Spain, Popoff in Russia, Schafer in Austria, Guarini in Belgium, and Ricaldoni in the Argentine Republic have all invented systems which have been more or less used in their respective countries. The Japanese have also devised a system that successfully stood the test of service in the Russo-Japanese war.

The development of the art in the various countries has been carried on largely by representative investigators, and in many instances the governments have adopted a system exploited by their subjects. The United States government, however, has purchased and experimented with most of the prominent systems offered, and as a result the army and navy equipments comprehend quite a variety of apparatus of different makes.

Telegraphic Codes. Before beginning the description of the more important systems of radiotelegraphy in use at the present time, we will consider the telegraphic codes employed in wireless correspondence. There are three alphabetical codes commonly used at the present time, viz, the Continental, the Morse, and the Navy codes. By far the greatest amount of business is carried on in the Continental code, especially between ships and shore stations. The Morse is more commonly employed for overland service, while the Navy code is confined to naval purposes. Abbreviations of the commoner words are often made use of in transacting the ordinary run of business. The three codes are shown in Figs. 55, 56, and 57.

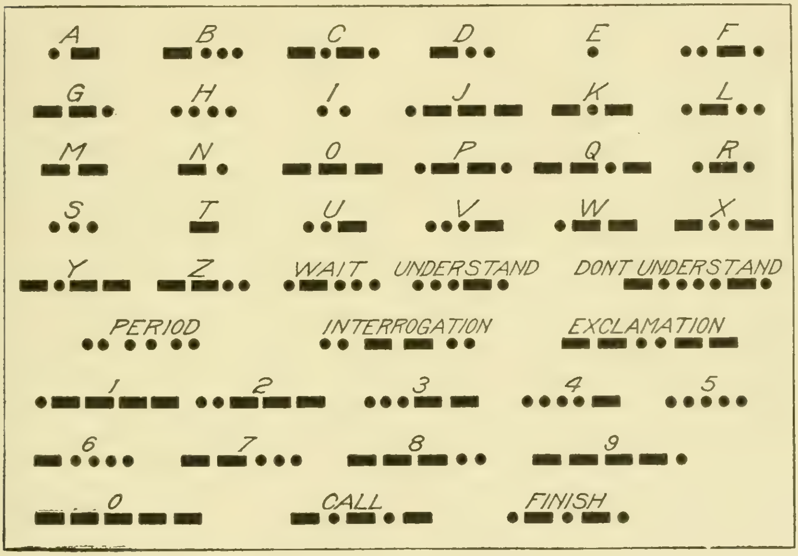
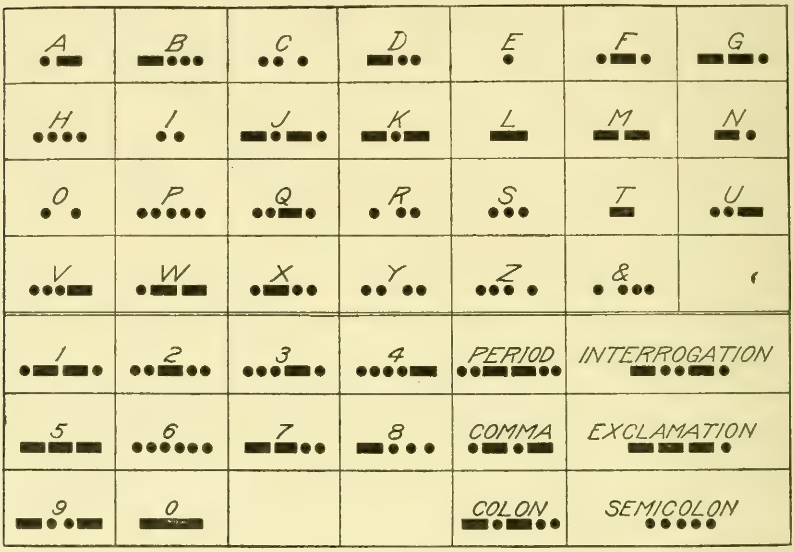


Fig. 55. Continental Code

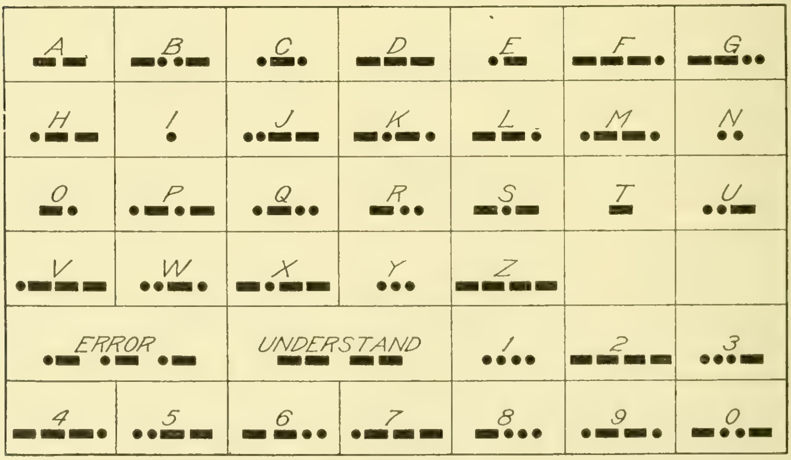
Marconi System. A detailed description has already been given of the Marconi system as it was about the year 1900. Since then the system has been developed to a remarkable degree so that it stands today a commercial factor of large pretensions. The Marconi stations are scattered in many parts of the globe and are operated in conjunction with all the large telegraph and cable companies.



A ·—	B —···	C ·· ·	D —··	E ·	F ·—·	G ——·
H ····	I ··	J —·—·	K —·—	L ⸺	M ——	N —·
O · ·	P ·····	Q ··—·	R · ··	S ···	T —	U ··—
V ···—	W ·——	X ·—··	Y ·· ··	Z ··· ·	& · ···	
1 ·——·	2 ··—··	3 ···—·	4 ····—	PERIOD ··——··	INTERROGATION —··—·	
5 ———	6 ······	7 ——··	8 —···	COMMA ·—·—	EXCLAMATION ———·	
9 —··—	0 ⸻			COLON —·—··	SEMICOLON ·····	

Fig. 56. Morse Code

In addition to the numerous land stations a very large number of vessels are equipped with the Marconi apparatus, including the



A ——	B —·· —	C ·—·	D ———	E ·—	F ———·	G ——··
H ·——	I ·	J ··——	K —·—·	L ——·	M ·——·	N ··
O —·	P ·—·—	Q ·—··	R —··	S —·—	T —	U ··—
V ·———	W ··—·	X —·——	Y ···	Z ————		
ERROR ·— ·— ·—		UNDERSTAND —— ——		1 ····	2 ————	3 ···—
4 ———·	5 ··——	6 ——··	7 ·———	8 —···	9 ·——·	0 —··—

Fig. 57. Navy Code

ocean liners of nearly all the large steamship companies, such as the Cunard line, the Hamburg-American line, the Norddeutscher Lloyd, and many other lines too numerous to mention. Three stations are in operation in China.

For short-distance equipment to be used over a few hundred miles, such, for instance, as is usually installed on Atlantic liners, the Marconi Company employs an induction coil with mechanical break to charge a battery of six to twelve Leyden jars. Two coils and two sets of jars are often supplied in order to readily produce two different wave-lengths. A single spark gap is now used. The Marconi magnetic detector is generally employed, owing to its great simplicity and ease of adjustment. An important improvement evolved by the meeting of practical difficulties is known as the *X-stopper*, *X* being the name given to certain irregular atmospheric disturbances of an electromagnetic nature which manifest themselves as stray signals of sufficient energy to cause confusion in the reception of messages. The means devised by Marconi for overcoming these objectionable interruptions may be seen in diagram in Fig. 58, which shows one form of the complete sending and receiving circuits employed by the Marconi Company. The lower end of the receiving aërial is connected with a plurality of adjustable oscillatory circuits of varying periodicity which terminate in the primary oscillation circuit of the receiving device. The operation of the contrivance depends upon the ability of the first three grounded circuits to perform the function of leading to the ground waves whose frequency does not accord with the periodicity of the system as a whole. It will be noted that the closed type of oscillatory circuit

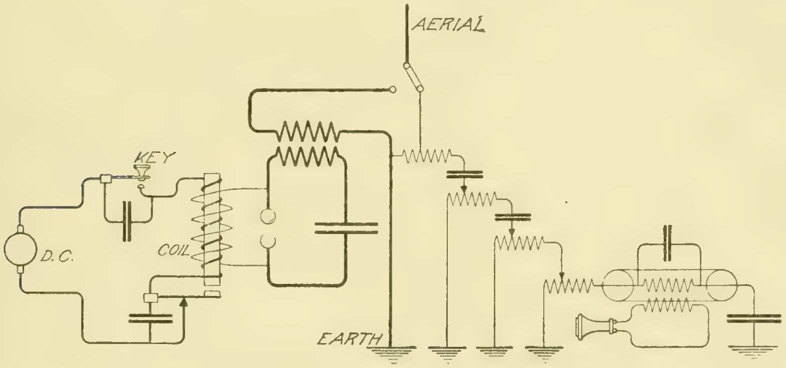


Fig. 58. Complete Marconi Sending and Receiving Circuit

inductively coupled to the aërial as before described is used in the transmitting arrangement of apparatus. The later form of oscillation transformer used at the sending station is designed to provide means for varying the closeness of the inductive couple. This possesses many advantages.

The Marconi Company has equipped several high-power trans-Atlantic stations. The modifications of the short-distance apparatus made necessary for long-distance signaling pertain largely to means for controlling a much larger amount of energy at the transmitting station and the employment of longer wave-lengths. Communication was established the latter part of 1907 between Cape Breton, Nova Scotia, and Clifden, Ireland, by waves 12,000 feet in length generated by means of the Marconi high-speed disk discharger used in conjunction with a condenser of 1.16 microfarads charged to 80,000 volts. Horizontal, or directive, antennae are used with their free ends directed away from each other at the two stations, the horizontal portion being about 1,000 feet long and raised about 200 feet in the air. The Marconi magnetic detector, and also a modification of the Fleming glow-lamp detector, have been used as receptors in this class of work.

An ingenious form of signaling key for use in connection with high-power installations employing alternating current has been patented by the Marconi Company. The fundamental feature of the invention consists in the use of a laminated electromagnet through which the current to be broken is conducted, so placed as to hold the key closed by the attraction of an armature on the key until the current reaches the zero value, at which time the key is allowed to break connection unaccompanied by a spark. The connection may be made and maintained at will, but upon release of the key the circuit is broken at the instant when the current reaches the zero value; the frequency of the alternating current being at least such that this occurs about 100 times per second, the maximum lag of the key behind the movement of the operator's button is inappreciable.

Fessenden System. Fessenden undoubtedly holds a position of first rank among scientific investigators in the field of electric radiation. Moreover, he has proven himself to be an inventor of exceptional originality. His experiments in radiotelegraphy date back to the early days of the art. The National Electric Signaling Company now control the long list of patents resulting from his researches beginning in 1897 and covering a great variety of subjects pertaining to every part of radiotelegraphic equipment as well as to radiotelephony.

The National Electric Signaling Company completed in 1905 two trans-Atlantic stations for communication between Brant Rock, Massachusetts, and Machrihanish, Kintyre, Scotland, a distance of more than 3,000 miles. Successful communication was established on Jan. 3rd, 1906, the detector used being the liquid barreter, already described. An interesting feature of these long-distance stations is the design of the aërial. This is in the form of a vertical steel tube 3 feet in diameter and 415 feet long, resting upon an insulated foundation, and supporting an "umbrella" formed of wires at the top. This structure is held in an erect position by sixteen guys insulated to withstand a voltage of over 150,000. A 25-kilowatt, 60-cycle, boiler-engine alternator supplies the energy.

Fessenden has devoted much time to the problems of selection, interference, and tuning. As a result of his labors in this field, the Fessenden system may be said to represent the highest development in this respect yet achieved.

The National Electric signaling equipment comprises a transmitting device of the direct-coupled aërial variety, characterized by the arrangement of the sending key which, by cutting out a certain amount of inductance in the oscillatory circuit, alters the frequency of the waves emitted—instead of interrupting the primary circuit and causing a cessation of the waves, as in common practice. This requires that a receiving station be tuned with great accuracy, in order to respond to a slight difference of wave-length only, an untuned circuit being thus unable to receive any signals other than a continuous dash. It is claimed that a difference of wave-length occasioned by the operation of the key, amounting to less than one per cent is sufficient to achieve perfect communication. This exceptional freedom from interference is due largely to the employment of what is called an *interference preventer*, diagrammatically represented in Fig. 59, which shows an improved Fessenden receiving circuit. The aërial is connected through a variable inductance to a divided circuit and thence to the ground. In each half of the divided circuit is placed a condenser in series with the primary of an air-core oscillation transformer. The secondary terminals of the transformer are united by a condenser *A*, a signal translating device consisting of the liquid barreter *B*, a potentiometer *C*, and a telephone receiver *D*—all in series. The secondary terminals of the transformers are connected up so as to oppose each other, after the manner of a Hughes induction balance. The aërial and one-half of the divided circuit are tuned to the desired frequency, the other half being momentarily disconnected; then the latter is connected again and the capacity of the condenser *E* is adjusted until the disturbing signals are eradicated. The operation is theoretically as follows: Signals of the proper wave-length pass almost entirely through the side of the divided circuit which is tuned to correspond, while waves of any other frequency pass with equal ease through both sides of the divided circuit, thereby acting differentially on the secondary oscillation circuit because the secondary windings of the oscillation transformers oppose each other. It is said that this arrangement will differentiate between waves differing but one per cent in wave-length.

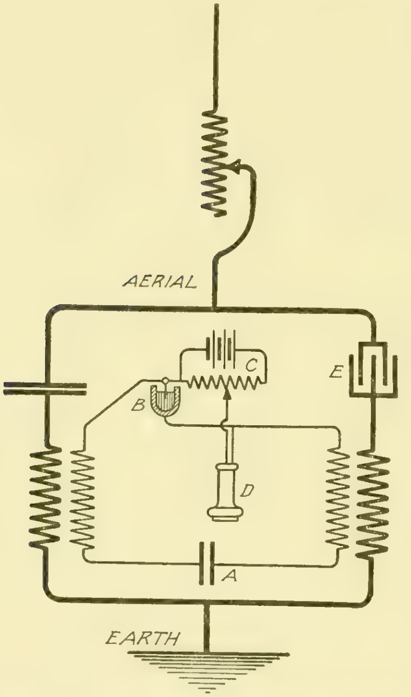


Fig. 53. Fessenden Interference Preventer

Fessenden apparatus is sometimes supplied with a so-called *intensity regulator* for modifying the intensity of radiation without affecting the frequency. This is for use in communicating with nearby stations.

Telefunken System. The system designated by this title is the result of an amalgamation of two formerly separate systems of radiotelegraphy. After patent litigation in the German courts, die Gesellschaft fur Drahtlose Telegraphie (Wireless Telegraph Co.) of

Berlin was formed to take over the conflicting interests represented by the Slaby-Arco system and the Braun-Siemens-Halske system. This company is operating under patents granted to Dr. Rudolph Slaby of Berlin, Count Georg von Arco, and Prof. Ferdinand Braun of the University of Strasburg, each of whom has made important contributions to the subject of space telegraphy. The Telefunken system has been developed to a remarkable degree, due largely no doubt to the powerful influence of the German government, and possesses stations all over the world—numbering more than 500.

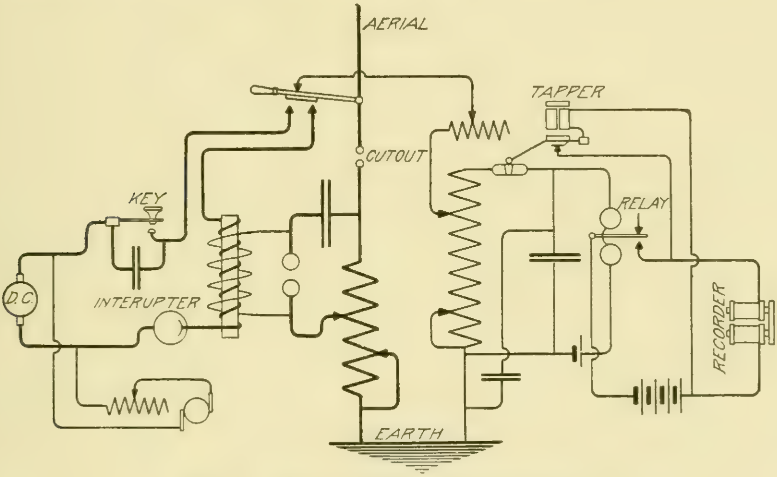


Fig. 60. Circuit Diagram, Telefunken System

Their equipment is sold outright and is noted for excellence of workmanship. The earlier sets of apparatus were furnished with a Morse recorder operated by a coherer of the nickel filings type, but latterly an electrolytic detector and head telephone are furnished as a means of reception. As the recorder and associated apparatus cut down the speed of signaling to a degree that seriously impairs their value for commercial work, the employment of the telephone is becoming almost universal practice. The recording mechanism is, however, preferred by many naval authorities over the telephone, as it eliminates the personal equation of the operator and leaves no possibility of error in the received messages.

A complete wiring diagram of the connections of the Telefunken system is shown in Fig. 60. The aërial is coupled directly onto the closed oscillatory circuit. A small air gap, or cut-out, is located in the transmitting aërial to prevent the received oscillations from flowing through the transmitting circuits. Such a gap offers no hindrance to the high-potential oscillations surging through the radiating circuit of the antennae. Means is shown for adjusting the inductance in the closed circuit of the transmitter, and the inductance between this circuit and the earth.

The Telefunken Company has more recently announced the so-called *singing-spark* system of radiotelegraphy, which is based on the discovery of Wein that exceedingly powerful discharges, possessing useful properties for radiotelegraphy, may be obtained from very short spark gaps. The air gap in this new modification of the Telefunken system is divided between a plurality of copper or silver disks kept apart by rings of mica. This form of oscillation generator is called by the German firm a *quenched spark.* When in operation the device gives forth a clear musical tone, which gives the system its name. The detector employed is of special design and said to be more sensitive than the electrolytic type. It is claimed for the singing-spark system that shorter aërials may be used and that a greater percentage of the energy of the source can be rendered available for radiation; also that the tuning of stations is greatly facilitated.

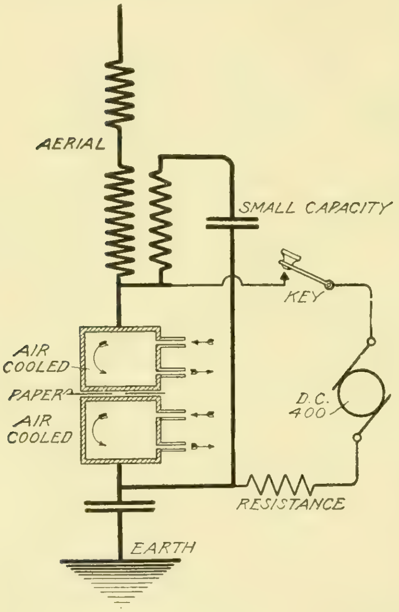
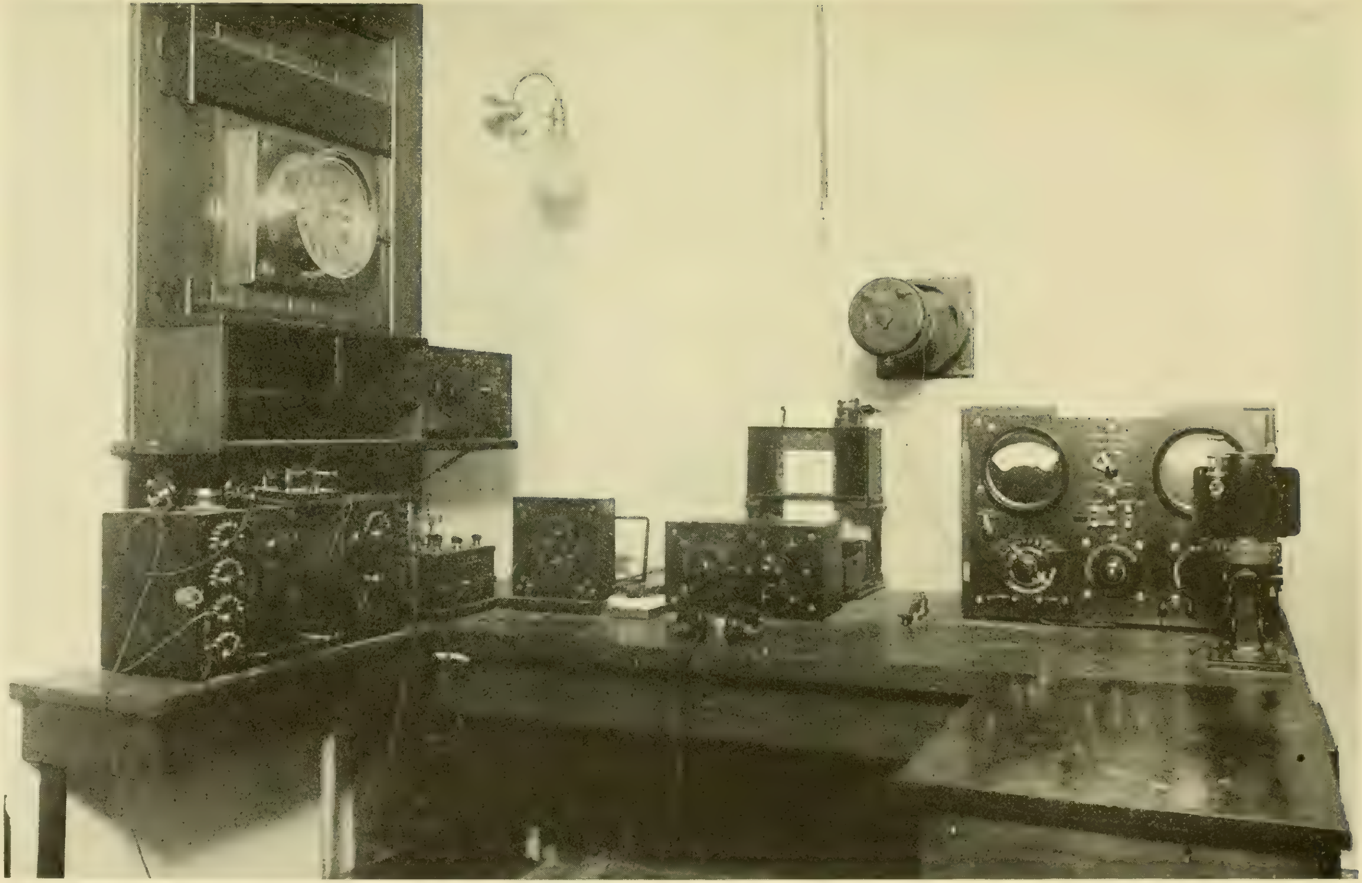


Fig. 61. Von Lepel Oscillation Generator Circuit

Von Lepel System. It has been claimed by the German experimenter, Von Lepel, that he applied the discovery of Wein to practical radiotelegraphy prior to its adoption by the Telefunken people. However this may be, the discovery referred to seems to be of importance, and though this method of producing oscillations is still in the experimental stage, the system of Von Lepel based thereon



RECEIVING ROOM OF THE GREAT GOVERNMENT WIRELESS STATION AT RADIO, VIRGINIA

Photograph by G. V. Buck, from Underwood & Underwood, New York

is of interest. The oscillation generator designed by him is shown in Fig. 61. It consists essentially of two copper-box, air-cooled electrodes about 5 inches in diameter, separated by a thin (.002 inch) disk of paper with a ½-inch hole in the center for the spark. The paper serves to keep the arc from running out to the edge of the electrodes. This paper constantly burns away, but a piece will last about three hours. The connections are indicated in the diagram, which shows a direct-current generator, but an alternating current will also operate the device. L and L' are inductively coupled inductances, the value of L' being very small. The capacity in series with L' and bridged across the gap is also very small. A satisfactory explanation accounting for the effects obtained has not yet been put forth. Tests thus far applied to this system have shown advantages not possessed by other systems; but it remains to be seen whether this idea is capable of the extended development it promises.

Lodge-Muirhead System. Reference has already been made to the great service rendered to the art of radiotelegraphy by Sir Oliver Lodge at that early time when its future depended on the elucidation of obscure theoretical points and on those important practical innovations which could alone make possible a commercial development of the idea. Lodge was very early impressed by the fact that periodic currents are amplified under conditions of resonance, and was of the opinion that wireless telegraphy by the early induction method could be facilitated by properly syntonizing the primary and the secondary circuits. He accordingly experimented in this direction and successfully verified his belief. He soon abandoned the notion of inductive telegraphy, however, and joined forces with Dr. Alexander Muirhead, endeavoring to effect wireless telegraphy by means of Hertzian waves. Always keenly aware of the advantages of syntony between the sending and the receiving apparatus, it is not surprising to find that his

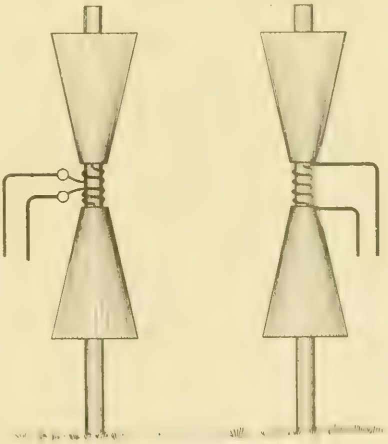


Fig. 62. Lodge Conical Capacity Areas

earliest patent specifications were very copious on this point. To facilitate accurate tuning, large conical capacity areas supported by a suitably insulated frame structure were employed, as shown in Fig. 62. This form of open oscillatory circuit later evolved into the horizontal wire areas now commonly associated with the Lodge-Muirhead system, which is further characterized by being "ungrounded," the lower capacity being in some cases placed several feet above the earth.

One form of a Lodge-Muirhead sending and receiving station is diagrammatically represented in Fig. 63, which makes clear the form of capacity areas more recently adopted. The transmitter is a form of direct-coupled closed oscillatory circuit, and the receiving circuit of the closed inductively coupled type. The auxiliary apparatus used in conjunction with the Lodge-Muirhead steel-disk coherer previously described is not shown in the drawing. Dr. Muirhead, endeavoring to render the system serviceable in connection with the ordinary forms of telegraphic signaling apparatus, has applied a syphon recorder directly connected with the coherer. A Morse register has also been employed, or a telephone, as occasion suggested. Automatic transmission by means of perforated tape is sometimes used, a perforator being furnished with their equipment.

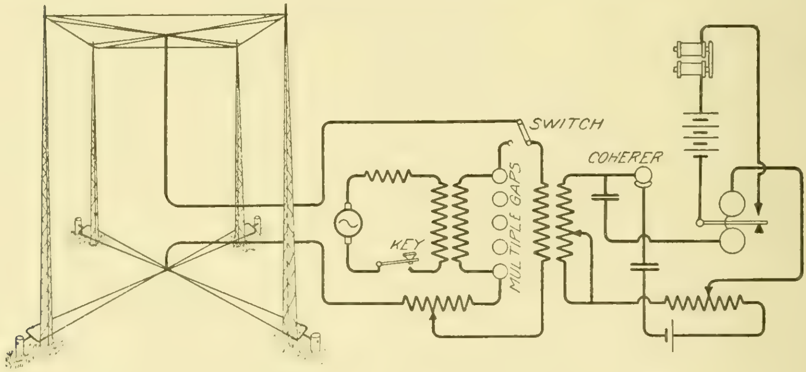


Fig. 63. Lodge-Muirhead Sending and Receiving Circuits

The Lodge-Muirhead system has never reached the large industrial development achieved by some other systems, notably the Marconi and the Telefunken; but it is, nevertheless, in commercial operation in many parts of the world. Communication was established in 1904 between the Andaman Islands and the mainland of Burma, and has given excellent service since. The distance is slightly over 300 miles. The adverse conditions incident to a tropical climate were here admirably met.

DeForest System. One of the best known American systems is that developed by Dr. Lee DeForest of Chicago. The DeForest interests have many stations located in the eastern States and along the Atlantic seaboard, one of the largest of which, located at Manhattan Beach near New York City, has successfully effected communication with Porto Rico and Colon, Panama, the latter a distance of more than 2,000 miles. A large number of merchant vessels are equipped with this make of apparatus. The United States navy also possesses a number of sets.

DeForest was among the first to employ an alternating-current transformer to charge the requisite capacity. The earlier form of his apparatus included a small motor-generator set delivering current at 500 volts, which was stepped up to 25,000 to 50,000 volts by means of an oil-immersed transformer, the secondary terminals being connected to the aërial and ground with condensers across a gap of the disk type. The receiver circuit used in conjunction with this apparatus was of the untuned kind, the detector being of an electrolytic nature called a "goo" responder, an invention of DeForest and E. H. Smythe. A "needle" anti-coherer of extreme simplicity was used with the earlier equipments, consisting of a light steel needle upheld by a retractile spring against two small aluminum rods. A telephone was employed to respond to the fluctuations of current in a local battery circuit caused by the increased resistance of the needle contacts under the action of the received oscillations. Great simplicity was aimed at in the design of the entire apparatus. No attempt was made to accomplish selection.

Electrolytic and thermo-electric detectors have been the subject of extended investigation by DeForest and his co-workers. As a result thereof a detector was evolved, consisting essentially of a small containing vessel filled with a suitable electrolyte into which projects the tip end of an exceedingly fine platinum wire. This "cell," under the influence of oscillations, exhibits a marked difference in its resistance to a local current. The similarity to the Fessenden liquid barreter is apparent. Much controversy has arisen relative to the theoretical operation of these detectors, DeForest contending that the action was electrolytic, while Fessenden and others have held to the view that the observed effect was due to the thermal action of the oscillations. Whatever the correct explanation may be, the fact remains that the "electrolytic" detector became, in the hands of DeForest, an exceedingly sensitive device and has contributed largely to the success of his system.

DeForest later devised a syntonized system based upon the principle involved in the so-called "Lecher Wires," which reflect waves bearing a definite ratio to the length of such wires. This arrangement, exhibiting anti-nodes of potential and current, possesses decided advantages when applied to the receiving circuit, as it permits a potentially-operable or current-actuated detector to be placed at a point of maximum effectiveness. Possessing also a very definite time-period, this form of circuit was found to lend itself admirably to tuning purposes.

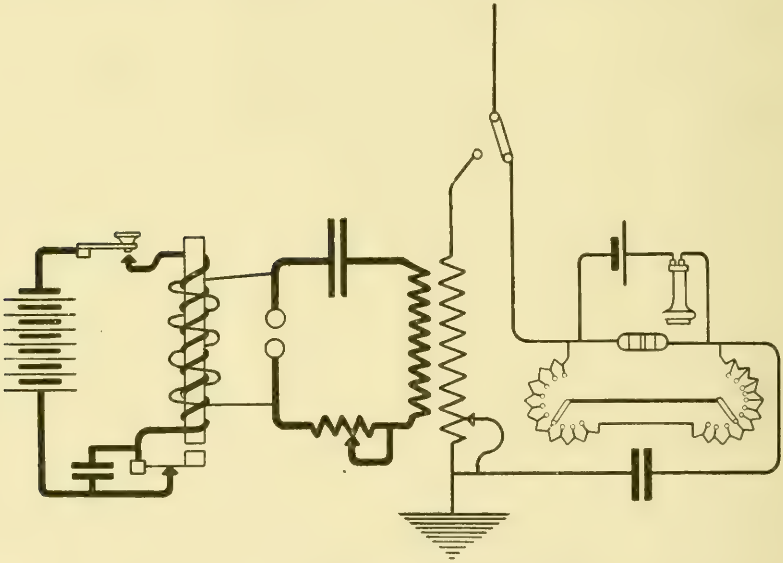


Fig. 64. Clark Sending and Receiving Circuits

Clark System. The Clark Engineering Company manufactures a form of radiotelegraphic apparatus designed by Thomas E. Clark, which is usually supplied as a portable equipment, contained in oak cases provided with shoulder straps for carrying. Many such sets have been purchased for the Signal Corps of the

United States army, for which service they are especially intended. The aërial wire is preferably raised by means of a kite. The transmitter is of the inductively coupled type, consisting of an induction coil, two one-half gallon Leyden jars, the oscillation transformer, and the necessary auxiliary apparatus, such as secondary batteries, an interrupter, etc. This portion of the equipment is made to be contained in three cases, while the receiving equipment is economically arranged within a fourth oak box covered with canvas. The receptor employed is of the auto-coherer variety, operating under the variations of resistance of the imperfect contact between two conducting plugs of steel with a small quantity of carbon granules interposed between them. A head telephone receiver and one dry-battery cell are shunted around the auto-coherer. The complete sending and receiving circuits of the Clark system are shown in Fig. 64. It will be noticed that the system presents nothing of novelty beyond the fact of its admirable adaptability to the requirements of a portable equipment. It can be readily packed on the back of a transport mule, or carried by men in a military campaign.

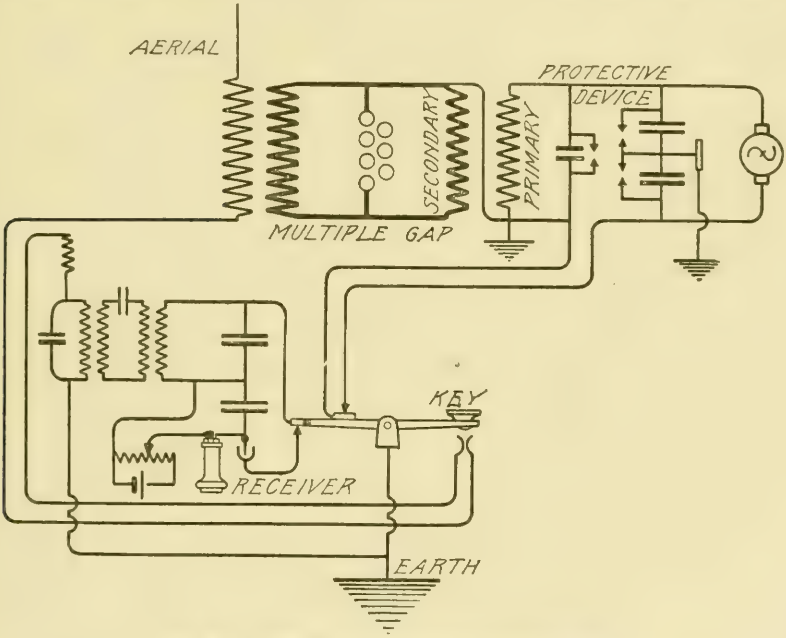


Fig. 65. Stone Sending and Receiving Circuits

Stone System. Another American system, which is curiously enough little referred to, is the Stone system, invented by J. S. Stone, who has been granted nearly one hundred patents in this country alone, besides their equivalents in European countries. His specifications cover the widest possible range of subjects pertaining to radio-telegraphy and proclaim him to be the possessor of an extraordinary understanding of the more recondite problems connected with the science. Several of his patents cover the inductive coupling of aërials, something after the manner of the Braun-Marconi method. It is difficult to believe that any large proportion of the specifications have ever been tried out in practice; in which case they may represent but "anticipatory" patents. One of the Stone arrangements for the sending and receiving stations is shown in Fig. 65, which embodies features of interest particularly from the viewpoint of the "wireless" operator. Reference is made to the multiple function of the sending key which allows an operator to be "broken in upon" while sending, by reason of the fact that the receiving circuit is broken by the depression of the key but instantly closed upon release. The aërial is inductively coupled to the closed oscillatory circuit containing a

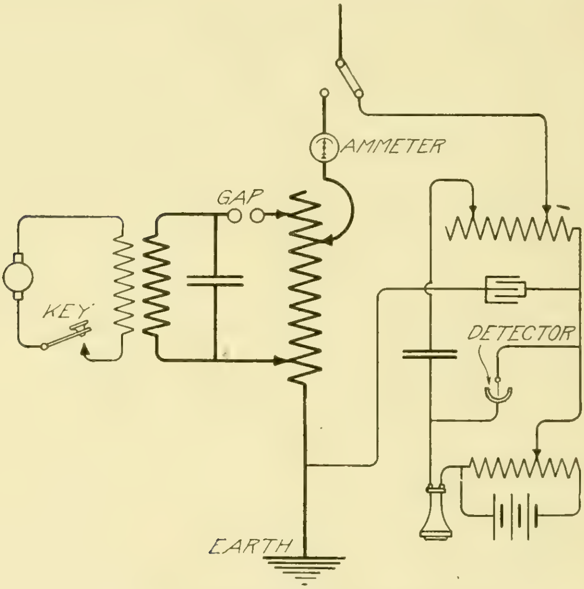


Fig. 66. Massie Sending and Receiving Circuits

multiple-spark gap. Various forms of detectors have been used by Stone, especially electrolytic and thermal devices. In one of his patent applications he describes a thermopile of platinum and gold for use as a detector. The Stone system has never been widely exploited although such equipments are occasionally used in this country and doubtless may be found elsewhere.

Massie System. Walter W. Massie of Providence, R. I., has developed a system of radiotelegraphy which bears his name. While the system has never been exploited on a large scale, numerous sets of apparatus have been purchased by the United States government, and many private concerns find use for this make of apparatus. Massie is well known among the amateur wireless experimenters as the inventor of an exceedingly simple detector of the imperfect contact type, which has rendered many a home-made outfit at least operative where a more complicated receptor would have been prohibitive. The device goes under the name of the *oscillaphone,* and consists simply of a common sewing needle placed carefully across two sharpened carbon edges. A small horseshoe magnet is sometimes located under the needle in order to exercise a slight attraction and maintain good connection. In the Massie equipments supplied for long-distance use, an electrolytic detector is employed. The Massie circuits are shown in Fig. 66. The aërial is direct-coupled.

Poulsen System. A remarkable system due to the genius of Valdemar Poulsen of Copenhagen has of late years attracted great attention, as it undoubtedly marks a decided advance in the art. Poulsen has accomplished by means of a modification in the Duddell arc a method of creating an almost continuous train of undamped oscillations resulting in an equivalent train of electric waves. The ability to generate such a persistent train of waves offers great advantages in the syntonization of stations and in the problem of selective signaling. As before mentioned, the Poulsen system is characterized by the employment of hydrogen under pressure as the surrounding medium for the arc. The receiving device used is the invention of Pederson, and a very full description of it may be obtained by referring to the *Electrician* for Nov. 16, 1906.

Other Systems and Inventors. Numerous other systems of radiotelegraphy have been exploited in various countries, but space will not permit of a detailed description of them here. The patent files of every government contain numberless specifications pertaining to the art; indeed, it is doubtful if any other improvement in electrical communication has called forth in so short a time a more voluminous patent literature.

The *Rochefort-Tissot system* in France has met with considerable success. Perhaps the most distinctive feature of this system is the form of induction coil employed, called a "unipolar transformer." The equipments are manufactured by Ducretet, the French instrument maker.

In Belgium the *Guarini system* has been installed in various localities with moderate success. The inventor has great faith in the possibility of relaying radiotelegraphic messages to accomplish long-distance transmission. He has devised a relay for such purposes, which seems to promise good results.

The Russian government has experimented with several systems, but the *Popoff system* is now almost exclusively used. Considerable interest attaches to this system on account of its historical importance. As early as 1895, Prof. Popoff communicated to the Physico-Chemical Society of St. Petersburg the details of a device employed by him for graphically registering atmospheric disturbances of an electrical nature by means of a coherer introduced between an elevated "exploring rod" and the ground. A relay and tapper were also employed, the former serving to operate a Richards register. It is thought by many that sufficient credit is not given Popoff for these innovations.

Sir H. M. Hozier and S. G. Brown in England have developed a system bearing their names, which differs little from the other systems, with the exception of the detector and method of directly connecting the same to a syphon recorder. The Hozier-Brown detector has been described elsewhere.

A system of selective signaling which seems to promise well, is that named after the inventor, Anders Bull. Resonance is not employed as a selective agency; instead, the receiver is designed to respond only to a group of wave-trains which are separated by certain unequal and predetermined intervals of time. The mechanism effecting the transmission of such properly timed wave groups is called the *dispenser,* and the companion device at the receiving end, the function of which is to translate the wave groups into printed

Morse characters, is called the *collector.* Tests conducted by the United States navy with this system were highly satisfactory as regards secrecy and freedom from atmospheric disturbances. The complicated nature of the apparatus will possibly prohibit the extensive use of this system, although it possesses advantages not even theoretically possible by resonance alone.

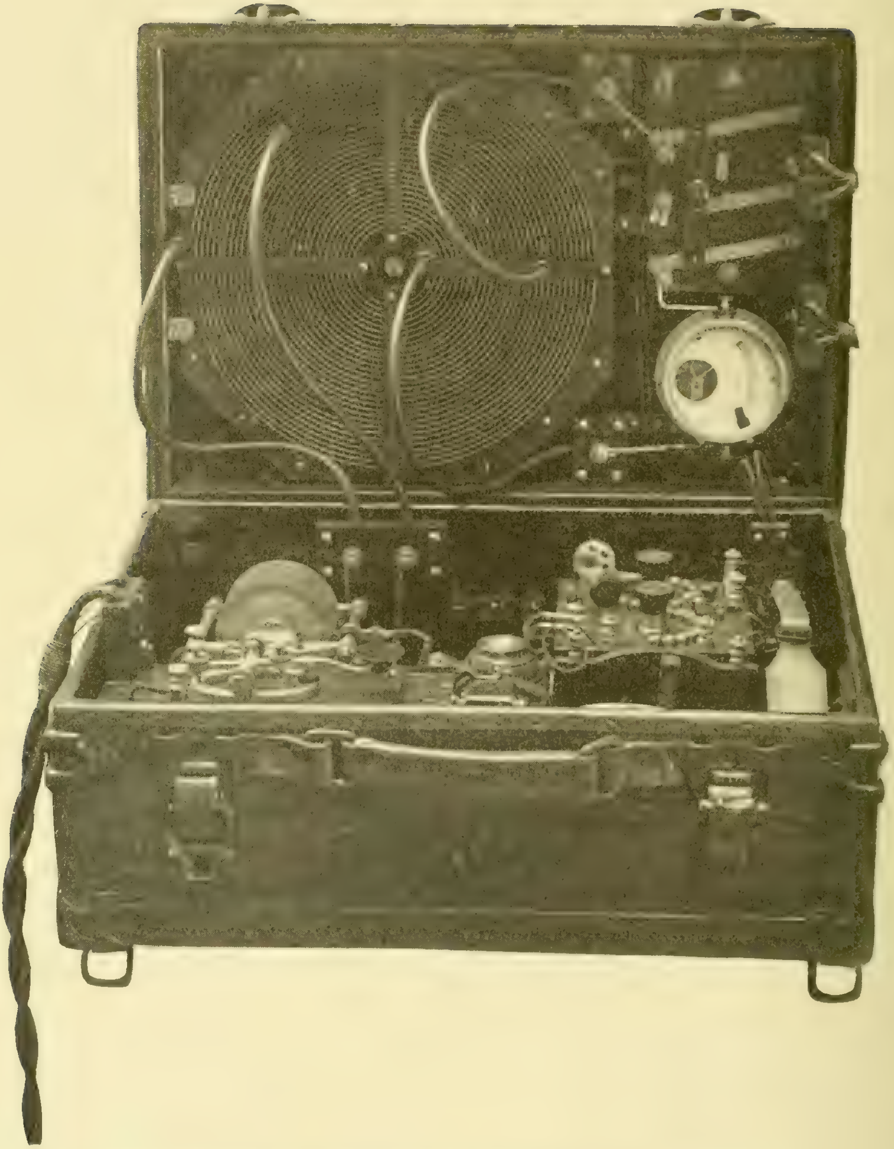
Conclusion. During the twenty years or so since Hertz made his famous discovery of electric waves, radiotelegraphy has made many substantial advances toward the goal of perfection; and it stands today a conspicuous and brilliant example among the many resources which Science has contributed to modern civilization. Its uses are many and important. To mention its life-saving power alone is to secure for it a high claim to consideration. Its success in this regard has been spectacular in more than one instance; and it is not too much to say that radiotelegraphy has saved hundreds of lives since the "wireless" installation of ships has become prevalent. To travel on the ocean with a "wireless" equipment on board, knowing that in case of peril the assistance of vessels within a radius of hundreds of miles can be instantly summoned, adds not a little to the comfort and security of the passenger. Radiotelegraphy may indeed be said to have struck a vital blow to the terrors of the sea. The sea, it would seem, has become the chosen sphere of wireless telegraphy, since it fills a want never supplied before. Formerly ocean-bound vessels were isolated from the world for days at a time; but now they can communicate with land or with other ships at almost any point in their course, some of the large ocean liners keeping in such close touch with events that they publish daily bulletins giving the world's latest news.

Another startling achievement of radiotelegraphy has been its success in effecting trans-Atlantic communication. Messages are sent between Europe and America across a void of air and water some 3,000 miles in extent. And they are not mere test messages, but regular press telegrams such as might be sent by cable. Here radiotelegraphy has become the direct rival of the old method of wire transmission. Whether the one will ever supersede the other is a question open to debate. The probabilities seem to be in favor of wireless, especially if the present rate of progress continues; but, for the present at least, there is room for both methods.

Wireless telegraphy promises to be of great service in times of war; in fact, all the leading nations have equipped their armies and navies with radiotelegraphic apparatus. Battleships will have a facility of communication never before possible, and land forces will be equally subserved. Heretofore, one of the first moves of a belligerent force was to cut the enemy's telegraph wires; but to cut off an electric wave will not be such an easy matter. The Japanese constantly made use of wireless telegraphy in the late war with Russia. The Japanese have their own method of effecting radiotelegraphic communication, the details of which are kept secret; but that it works successfully, they have well demonstrated.

Concerning the utility of radiotelegraphy for communicating across land areas, much that is favorable and promising can be recorded; but there is still something to be desired with respect to ease and certainty of operation. The progress thus far made has brought to light many problems which await solution and recorded many phenomena relative to transmission over long distances, especially over land, which cannot as yet be accounted for or controlled. The screening effect of intervening mountains and cliffs exercises a marked difference in the energy of the received signals; long stretches of exceptionally dry ground seem to have the same effect. This probably accounts for the fact that the greatest distances to which signaling has been carried have been over salt water. Signals seem to be more easily effected at night than in daylight; so marked is this effect that communication carried on with perfect success at night has often been permanently interrupted by the advent of daylight only to be resumed the following night. J. J. Thomson has put forward a possible explanation of this, but space forbids its inclusion here. Again, certain conditions of the atmosphere seem to render but comparatively small energy necessary in the accomplishment of long distances at times.

Thus radiotelegraphy, like all forms of telegraphy, as well as telephony, has its limitations and unsolved problems; but, judging by past achievements, it is not well to dogmatize too emphatically as to the finality of these limits.



PORTABLE WIRELESS SET DESIGNED BY UNITED STATES ARMY EXPERTS

Photograph by Waldon Fawcett, Washington, D. C.

WIRELESS TELEPHONY

Wireless telephony is not so new almost unborn, indeed — as is generally supposed. Like its companion art, wireless telegraphy, it began its existence well back in the nineteenth century. Its inception is contemporaneous with that of wire telephony, for Alexander Graham Bell was the originator of both. It is a singular coincidence that Bell, the inventor of the telephone, and Morse, the reputed inventor of the telegraph, should each have been among the first to accomplish their respective modes of communication wirelessly. The history of wireless telephony follows very closely that of wireless telegraphy. The extreme sensitiveness of the telephone receiver to small variations of current very naturally suggested its employment as a receiving device in connection with the inductive and conductive methods of wireless telegraphy, and attempts were made at an early date to accomplish the transmission of articulate speech by these same means. The results obtained however, were very meager; the inherent difficulties characterizing these methods proved to be even greater with the application of telephone principles, due to the diminution of energy made necessary by the nature of the process. As in the case of wireless telegraphy, the solution of the problem lay in the application of the method of electric radiation.

Bell's Radiophone. One of the earliest attempts at radiotelephony was not of an electrical nature, judging by the usual appearances, but depended on the thermal effect of a variable beam of light directed upon bits of burnt cork enclosed in a small glass tube to which was connected a rubber tube to be inserted in the ear of a listener. This device is shown in Fig. 1. The light from a convenient source was reflected from a thin silvered diaphragm and caused to fall upon the burnt cork. When this diaphragm was set into vibration through the agency of the voice, the light reflected therefrom was subjected to a corresponding variation of intensity, and, being directed upon the blackened cork, produced therein minute changes of volume due to the variations of temperature;

and such changes produced air-waves which were manifested in the form of sound and audible within the tube. This simple device, invented by Alexander Graham Bell, was called by him a *radiophone.* He later greatly improved the apparatus by substituting selenium as the means of reception, the peculiar electrical property of which substance was then first attracting attention.

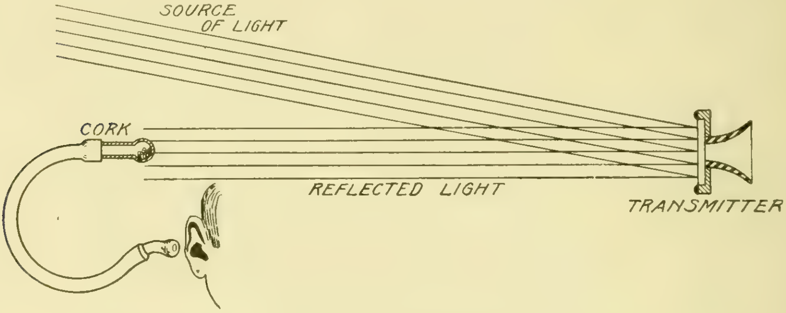


Fig. 1. Bell's Radiophone

Selenium Cell. In 1873, Willoughby Smith discovered that the resistance of metallic selenium was greatly reduced by exposure to light. The light from a small gas burner was found to exercise a marked influence on the conductivity of short rods of selenium used as resistances in a series of cable tests then in progress. The discovery caused widespread interest in the scientific world. Among the many men attracted by this peculiar property of selenium was Prof. Bell, who, in conjunction with Sumner Tainter, succeeded in producing the first useful so-called "selenium cell." This device consists essentially of selenium spread over the surface presented by the edges of alternate disks of metal separated by thin sheets of mica after the manner of a condenser, thereby greatly enlarging the area of contact between the selenium and the electrodes formed by the alternate disks. By connecting such a cell in series with a battery and telephone receiver, the current passing through the circuit is largely dependent upon the degree of conductivity possessed by the selenium cell, which in turn depends upon the amount of light falling thereon. Any variation of the light directed upon the cell is, therefore, capable of causing a corresponding variation of the current flowing through the receiver, with the result that such variations become audible therein.

Bell's Photophone. In 1878 Bell put forward a most ingenious application of the selenium cell for the purposes of radiotelephony, which he called a *photophone.* The arrangement of apparatus is shown in Fig. 2. The selenium cell C is placed in the focus of a parabolic reflector R and is thus interposed in the path of the rays reflected by the mirrored surface of a diaphragm D from any suitable source of light S. The resistance of the selenium cell was approximately 1,200 ohms in darkness, and about half that when fully illuminated. The mode of speech-transmission is so similar to that of the radiophone that further description is not necessary.

The photophone, as proposed by Bell, may be made to transmit speech perfectly over short distances, but it is obviously limited by reason of the inefficient means employed to effect the variation of the intensity of a source of light. As the employment of the device for distances relatively long necessitated the use of powerful sources of light and adequate means for controlling the same, the invention remained but a beautiful laboratory experiment until the discovery of the speaking arc by Simon in 1897 opened up the possibility of future development.

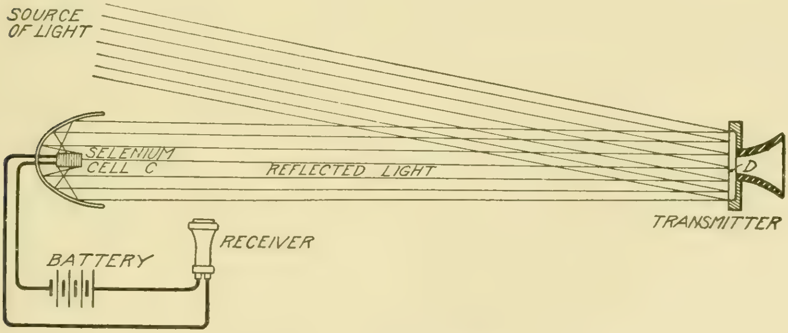
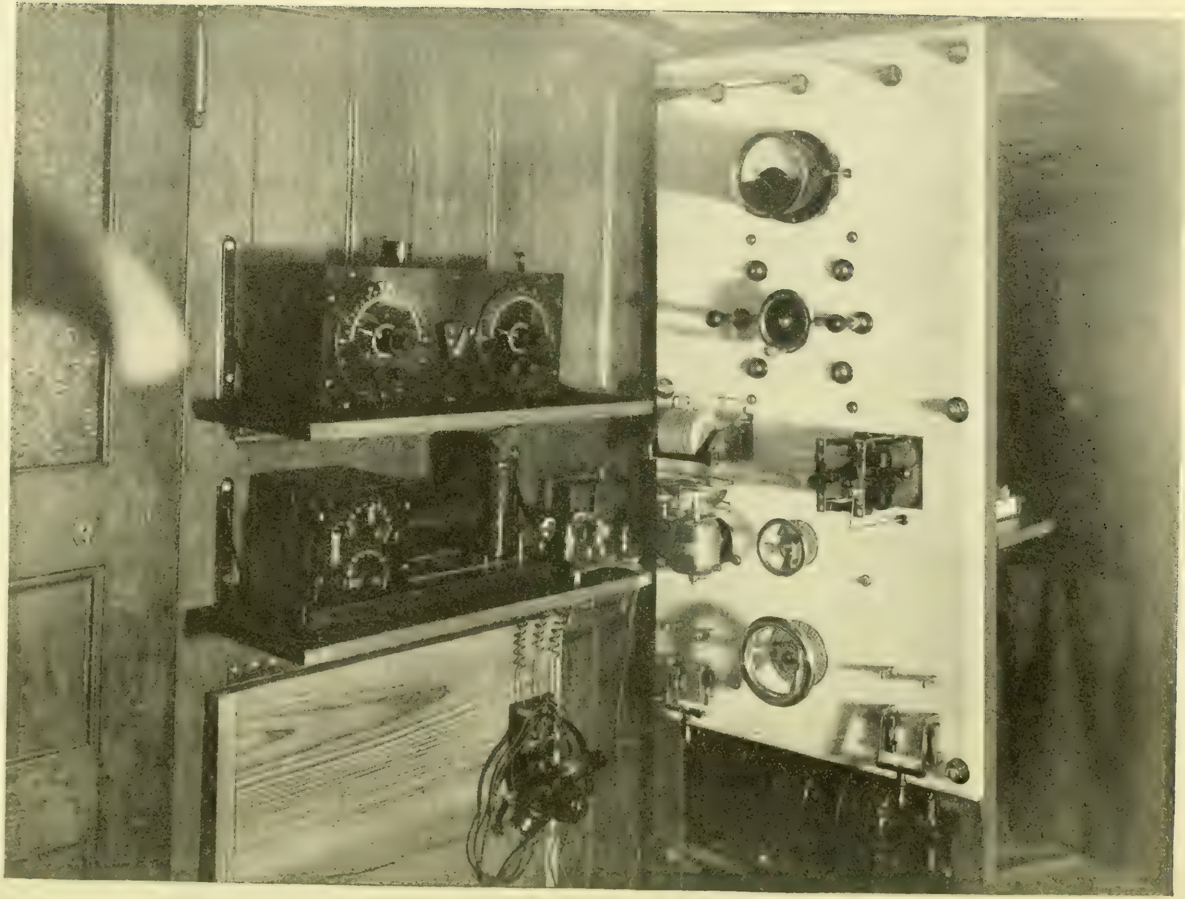


Fig. 2. Bell's Photophone

"Light Telephony." Prof. H. T. Simon of the Physical Institute of the University of Erlangen discovered, toward the end of the year 1897, that a direct-current arc may be made to give forth musical tones and even speech by superimposing a telephonic voice current upon the arc current. This discovery suggested the possibility of using Simon's arc as a transmitting arrangement for the Bell photophone. With this end in view, numerous experiments were carried on, principally in Germany, aiming to increase the efficiency of the apparatus when operated in conjunction with powerful searchlights, and also to develop the selenium cell to a point of greater sensitiveness. Wireless telephonic communication by this means has become known as *light telephony*, and has reached its highest development in the hands of that most ingenious German investigator, Ernst Ruhmer. The German navy has several vessels equipped with the Ruhmer apparatus for intercommunication. It is said that a distance of twenty miles is, under favorable weather conditions, the limit of operativeness with this form of radiotelephony. The use of the system is necessarily restricted to open spaces, and dependent upon clear atmosphere.

Telephony by Means of Hertzian Waves. The success achieved by Marconi in telegraphing without wires inspired many investigators to apply the Hertzian-wave method to the problem of telephony. As early as 1897 various workers became imbued with the idea and, as a result, a number of systems of radiotelephony have grown up contemporaneously with those of radiotelegraphy. It cannot be said, however, that the results accomplished by the early experimenters in this field gave more than a promise of future usefulness for this method of communication, the distances covered being extremely small in proportion to the complexity of the apparatus involved. In many instances, however, the inventors of such systems had a clear perception of the fundamental requirements, and felt confident that the development of the art on its practical side would ultimately make possible a successful application of their theories.

The principal difficulty encountered in the application of Hertzian waves to the problems of telephony was found at the start to reside in the transmitting portion of the apparatus. The receiving end offered no great obstacle, since it was known at an early date that many of the detectors used in connection with radiotelegraphy would prove suitable for the reception of speech—providing that a means could be discovered to effect the emission of wave-trains whose energy should vary in accordance with the vibrations of the human voice. The fundamental problem of radiotelephony is practically the same as that met with in ordinary wire telephony—*to cause a*



REMARKABLY COMPACT RADIO TELEGRAPH SET INSTALLED BY GOVERNMENT EXPERTS ON THE "TARRAGON," THE GOVERNMENT INSPECTION LAUNCH

Photograph by Waldon Fawcett

distant diaphragm to repeat sympathetically the vibrations of a diaphragm against which the energy of the sounds to be transmitted is directed. In both cases the efficiency of the various transformations of energy involved in the process is of prime importance. The current-carrying capacity of the carbon transmitter places a limit on the amount of energy possible to utilize telephonically. This restriction is felt to a marked degree when the device is associated with the necessarily large amount of energy required for Hertzian-wave radiation over any considerable distance. In view of the foregoing, it is not surprising to find that early experiments in radiotelephony were directed almost exclusively toward a solution of the problem of an efficient transmitting apparatus.

Many attempts were made to accomplish this end by placing the ordinary microphone transmitter in the primary of an induction coil, thus serving the purpose of an interrupter, as exemplified in Dolbear's early wireless telegraph system. Such experiments only sufficed to show that nothing was to be gained in this way, largely by reason of the before-mentioned inherent limitations of the telephone transmitter. The problem was then attacked in another manner, viz, by endeavoring to modify telephonically a train of waves of a constant intermittency radiating from a continuously operating source of oscillations, such, for instance, as a simple radiotelegraphic transmitter without a primary signaling key. Though this method allowed a much greater amount of energy to be utilized, it soon became evident that a grave difficulty was presented due to the nature of the radiations from such an arrangement. The train of waves thus generated is not continuous, but consists of intermittent wave-trains separated by short periods of time during which no radiation takes place. These breaks in the continuity of the train are often of greater duration than the individual oscillations due to one complete discharge of the condenser; they consequently produce in the telephone receiver a continuous buzz which seriously interferes with the audibility of the received voice vibrations. As the timbre of the human voice depends upon overtones and upper harmonies of a frequency of from 5,000 to 8,000 or more, the pauses between oscillation trains also interfere with clear articulation whenever their frequency drops much below 10,000 per second. At frequencies of from 20,000 to 50,000, however, this feature ceases to be a hindrance. The success of the method of telephonically varying the energy emitted from a continuously operating source of radiation was seen, therefore, to depend upon the possibility of producing more perfectly sustained oscillations of high frequency. The means for creating oscillations that are undamped and practically continuous, may be considered the greatest problem of radiotelephony relative to transmission. At the present time there are two methods of accomplishing such persistent radiations, viz, by employing the high-frequency alternator, or by using some form of the oscillating arc. The last-named method has been developed, under the ministrations of Valdemar Poulsen, to a degree of efficiency that promises to place radiotelephony on a commercial basis. The alternator method has been persistently favored by Prof. R. A. Fessenden, who has accomplished some remarkable results. Both methods have their staunch advocates, each possessing its own peculiar advantages as well as limitations.

Nature of a High-Frequency Telephone Current. The foregoing paragraphs have indicated briefly the general theory upon which the most successful systems of radiotelephony have been developed. It remains to consider in more detail the nature of the action involved when a uniform flow of undamped oscillations is modified by the variations of a voice current.

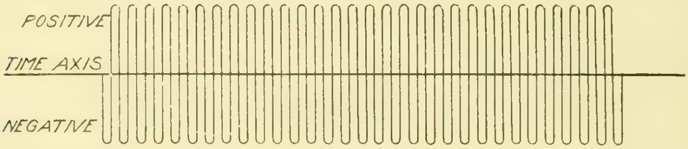


Fig. 3. Diagram Representing High-Frequency Current

It is convenient for a ready understanding of the matter to first consider the case of a high-frequency alternator supplying a constant alternating current of a periodicity somewhat above human audibility—say 50,000 cycles per second. Supposing such a current to be flowing through a variable resistance such as a telephone transmitter, the effect of an increase of the resistance thereof manifests itself by a lessening of the amplitude of each individual half-wave of current; while, conversely, a decrease of the resistance manifests itself by an amplification of the current half-waves. When, therefore, the resistance is made to vary with great rapidity, as when the diaphragm of the transmitter is thrown into vibration by sound, the effect upon the alternating current flowing therein is to produce a corresponding change in the maximum value of each half-wave.

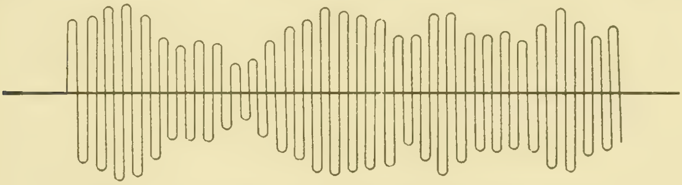


Fig. 4. Diagram Representing Variations of Amplitude

As the energy of each half-wave may be represented by its amplitude, it is evident that an alternating current varying in this manner exhibits a wave-form of energy equivalent in many respects to a direct current similarly modified. Figs. 3 and 4 illustrate this idea, Fig. 3 representing the steady alternating current permitted by the normal resistance of a transmitter; and Fig. 4 showing the alterations of amplitude thereof occasioned by the variations of resistance in the said transmitter. It will be noticed that the maximum instantaneous values may be greater than normal, as well as less, due to the fact that the resistance of a transmitter when spoken into varies between limits above and below its resistance when at rest. Some idea of the complexity of the action taking place under the conditions of actual practice may be had by referring to the wave-form shown in Fig. 5, which represents the current curve, or oscillagram, of a telephone current produced by the vowel, long ō, spoken into the transmitter. In forming a mental conception of the wave-form resulting from the superimposing of a telephonic voice current upon a high-frequency oscillating current, the enormous difference in their respective periodicities must be borne in mind.

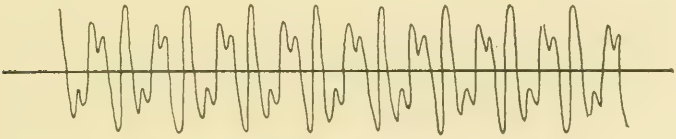


Fig. 5. Oscillagram of a Telephone Current

In the case of an oscillation generating arrangement which does not produce a perfectly sustained train of electric waves but a series of partially damped wave-trains separated by slight breaks of continuity, the essential condition for success in connection with radiotelephonic work is that the interruptions shall not take place at an audible frequency. It is highly probable that the direct-current arc method of creating oscillations does not produce an absolutely continuous train of waves, as is the case with a high-frequency alternator, but, on the contrary, is made up of a great number of groups of almost undamped oscillations separated by an interval of time, very small even in comparison with the duration of each group.

Oscillation Generators. An account has already been given, in the pages devoted to Radiotelegraphy, of the attempts which have been made to construct high-frequency alternators for use in the production of continuous, undamped oscillations, and some description given of such machines. Reference has also been made to the development of the direct-current arc method of producing a similar result. In the present instance it is not deemed necessary to dwell on these subjects further than to give some notion of the particular devices constructed for use in connection with the most successful systems of radiotelephony, and to mention those modifications of the arc method which have been found to give the best results in this field of use.

Undoubtedly the most successful high-frequency alternators have been those constructed by Prof. Fessenden for use in his extensive experiments in radiotelephony carried on at the Brant Rock (Mass.) Station of the National Electric Signaling Company. This inventor has devised several such machines, one of them having an output of 2 kilowatts operating at 80,000 cycles, and a voltage of 225 volts. This machine was of the double armature type with 300 teeth on each, direct-coupled to a DeLeval turbine. A similar generator designed for use on shipboard and run by a turbine is capable of developing 3 kilowatts at a frequency of about 100,000 cycles. Fessenden has also designed a 10-kilowatt machine of a periodicity of 100,000 per second. The problem of properly designing such generating units and constructing them on a commercial basis cannot as yet be said to be satisfactorily solved; it is generally felt, however, that the solution of the problem will be effected at no distant date, at which time this method of producing the requisite oscillations for electric-wave communication will supersede in many instances the more complicated and less constant methods now in use.

There are in use at the present time various arrangements of the direct-current arc employed as a means of creating alternating currents of great frequency, all of which depend for their operation upon the principle of the Duddell arc but differing in the details of application. One of the earliest and most successful of these is due to Poulsen, who achieves extremely high-frequency oscillations of great energy by causing the arc to take place between copper and carbon electrodes enclosed in a chamber containing hydrocarbon gas. In order to increase the energy of radiation, Poulsen later employed several arcs in series. This is known as the multiple-arc system, and has been developed to a high degree by die Gesellschaft fur Drahtlose Telegraphie of Berlin.

Telephonic Control of Oscillations. Radiotelephony figuratively substitutes in place of the metallic line of ordinary telephone practice a continuous stream of electric waves of approximately uniform strength. By varying from instant to instant the energy of this stream of waves in accordance with the variations of air-pressure acting against a transmitting diaphragm, a transference of such energy-variations is effected between two stations. By the employment of suitable translating devices, the energy-vibrations of the wave-stream may be made to undergo a transformation resulting in the movement of a second diaphragm which exactly duplicates the vibrations of the first, and the variations of air-pressure occasioned thereby complete the cycle of energy-transformations from sound to sound.

It is to be noted in connection with the foregoing analysis that it is not the entire amount of energy of the flow of waves between stations that is available for transformation into sound at the receiving end, but only the energy represented by the *variations* of this flow of waves. Thus the problem of telephonically controlling a large amount of energy for efficient radiotelephonic transmission is to effect, by means of the energy of the voice vibrations, a maximum percentage of variation in the energy radiated. With the methods employed at the present time there are reasons for believing that this percentage does not greatly exceed 5 to 8 per cent of the total energy.

In this respect radiotelephony differs very widely from radiotelegraphy, for with the latter the entire energy of radiation is available to the limit of our ability to detect it. Some of the inventors claim a greater percentage of efficiency for their respective systems of radiotelephony. Fessenden has devised an improved form of transmitter which he states produces much better results.

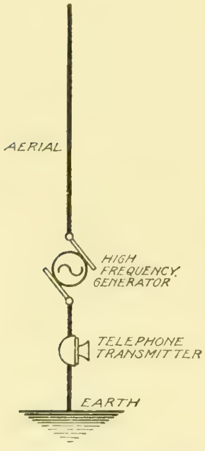


Fig. 6. A Form of Fessenden Circuit

There are several ways of modifying the electric oscillations set up in a transmitting arrangement for the purposes of radiotelephony. The method generally employed involves the use of some form of carbon transmitter whereby the variations of its resistance under the influence of the energy of the voice are made to vary the oscillatory current directly, or a local-battery circuit similarly affected is inductively associated with the oscillatory circuit. Variations in the emitted wave-train may also be accomplished by the use of a condenser transmitter formed by a thin metallic diaphragm separated from a metallic plate by a thin layer of air acting as dielectric, the vibrations of said diaphragm producing variations of capacity between the two surfaces. This variable capacity is used to throw the aërial in and out of tune. The inductance of an oscillatory circuit may also be made to vary by means of the voice and produce a like result. One of the earliest suggestions relating to the telephonic control of the energy of oscillations was made by an Italian, Lonardi, who, in 1897, proposed that the spark balls of a Righi oscillator connected to a source of constant potential be made to vibrate by the voice, thereby altering the length of the spark gap and causing the oscillator to be charged to greater or lesser potentials, and thus varying the energy of the emitted waves.

Transmitting Circuits. One of the simplest and earliest circuits patented for use in connection with radiotelephony is shown in Fig. 6. It is due to Fessenden, and consists of a high-frequency alternator connected in series with an aërial, a telephone transmitter, and the ground. The time-period of the radiating circuit thus formed is adjusted to the periodicity of the dynamo.

The patent application on this arrangement was filed in 1901 at a time when it is generally believed that the creation of electric waves necessitated an abrupt release of energy, as exhibited by the discharge of a condenser. In experiments carried on with this arrangement in 1906, a distance of about ten miles was covered, the generator running at 10,000 revolutions per minute and developing 50 watts at 80,000 cycles per second. The resistance of the armature was about 6 ohms. An electrolytic cell was used for a detector.

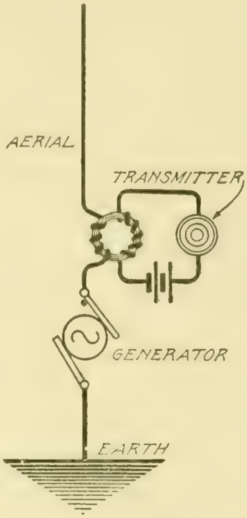


Fig. 7. Transmitter Inductively Associated with Aërial

Another method of effecting the telephonic variation of an oscillatory system is shown in Fig. 7. The aërial is connected to the secondary of a small transformer, the primary winding of the same being included in a local-battery transmitter circuit.

An arrangement for use with the arc form of oscillation generator is shown in Fig. 8. Direct current for the arc is supplied to the terminals of the closed oscillating circuit through the secondary of a transformer, the primary circuit of which contains a carbon transmitter and local battery. The fluctuations of intensity of the oscillations may be effected in a manner diagrammatically shown in

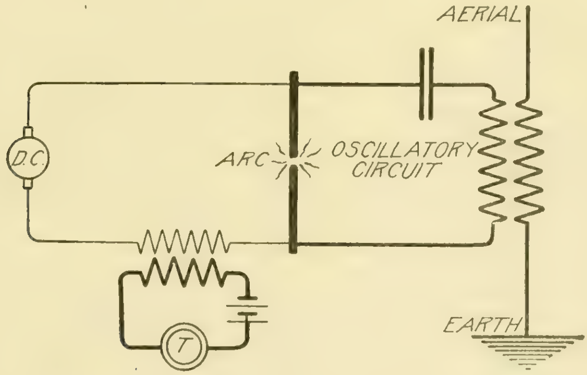


Fig 8. Transmitter Associated with the Supply Circuit

Fig. 9, where the inductive method of superimposing the telephone current from a local circuit is applied directly to the closed oscillatory circuit. Inductances *I* and *I′* inserted in the supply mains prevent the voice current from passing around through the source of supply.

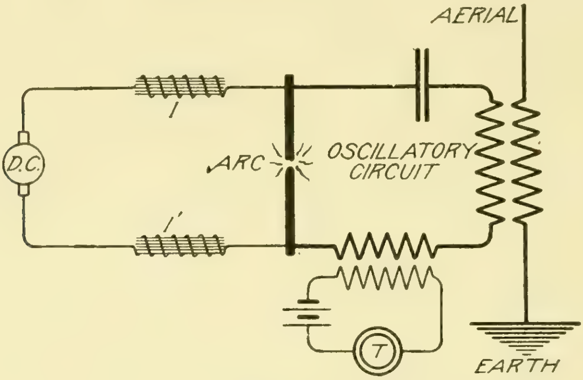


Fig. 9. Transmitter Inductively Associated with the Closed Oscillatory Circuit

In Fig. 10 is shown still another method of locating the variable-resistance member, viz, by shunting the secondary of the oscillation transformer employed in connection with an inductively coupled aërial. The telephone transmitter may also be used with a directly coupled aërial by causing it to vary the effective turns of a portion of the inductance included in the open radiating circuit, as in Fig. 11.

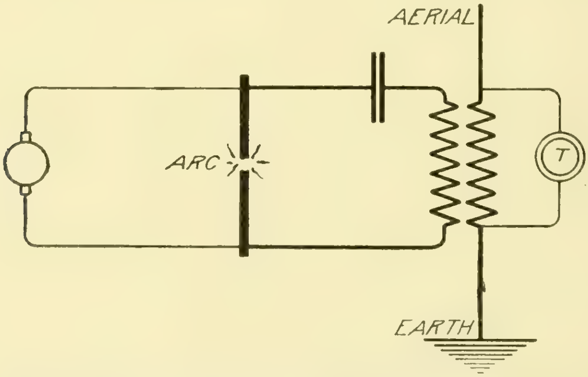


Fig. 10. Transmitter Shunted across the Aërial Inductance

From the circuits here given, it is evident that the conditions essential to telephony are fulfilled when the transmitter is so placed as to produce by its action a change of the electrical properties of the radiating aërial; and experience has shown that this may be accomplished with the microphonic, or carbon, transmitter in a variety of ways, many of which seem to operate with equally good effect. The condenser, or variable-capacity, transmitter is effectively operative only in conjunction with the oscillatory portions of the sending circuit, usually as a shunt. One method of placing this form of transmitter is shown in Fig. 12, which arrangement has been employed by Fessenden.

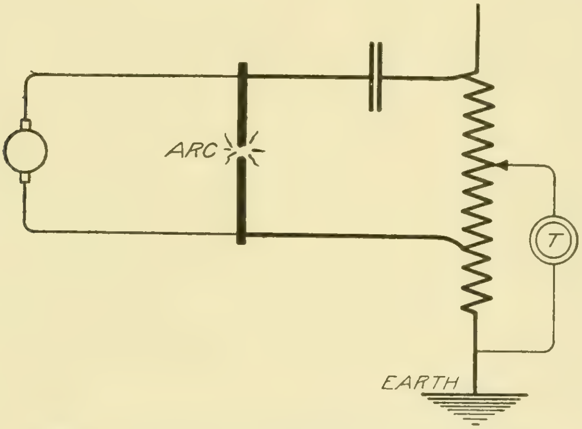


Fig. 11. Transmitter Shunted across a Portion of the Aërial Inductance

As before remarked, the small current-carrying capacity of the microphonic transmitter has proved to be a great obstacle to the rapid development of the art of radiotelephony as a commercial proposition; and it may be said that until an efficient means is devised for overcoming this difficulty, and thereby greatly increasing the percentage of variation in the intensity of the oscillations, or the equivalent thereof, the sphere of usefulness for this form of wireless communication will be much restricted. Many attempts have been made to effect this improvement by connecting several transmitters in multiple to be acted on by a common mouthpiece. Various so-called telephonic repeaters have also been devised purporting to accomplish an increase in the amplitude of the telephonic current Such devices, however, have not proved to be a satisfactory solution of the problem, although Fessenden claims to be able to effect a decided amplification with an instrument of the latter character designed by himself. This ingenious investigator has undoubtedly constructed an instrument more nearly fulfilling the requirements of a transmitter adapted to this class of work than any heretofore presented. It is called by him a "trough" transmitter, and is said to be able to carry continuously more than 10 amperes. The electrodes are water-jacketed The amount of variation in a current of this magnitude, produced by the action of the voice, is of course the important factor. The results accomplished by the "trough" transmitter indicate a decided gain over the form commonly employed. Further radical improvements in transmitter design may be confidently expected from the numerous experimenters whose inventive ability is now being brought to bear on the problem.

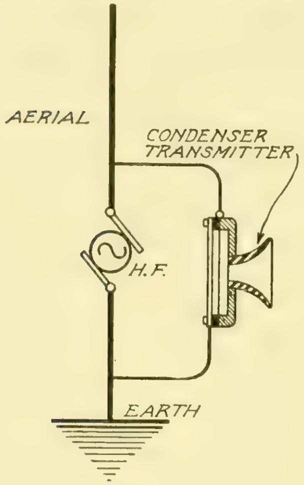


Fig. 12. Condenser Transmitter

Receiving Arrangements. For purposes of radiotelephony the detectors depending upon mere potential for their operation, such as the early forms of coherer, are practically useless. The essential characteristic which a detector suitable for this class of work must possess is that it shall not only respond to the received oscillations, but that it shall be affected to a certain extent in proportion to the amplitude of such oscillations. In short, radiotelephony requires a form of detector which is quantitative, that is, one which will respond to the varying integral value of the oscillating current. Such devices as the thermo-electric, electrolytic, ionized gas, and crystal-valve detectors are all of this type, and may be used for the reception of speech when properly connected with a telephone receiver. This quantitative function may be elucidated by considering the action of a thermo-electric detector properly associated with a tuned receiving circuit. If a continuous train of undamped waves falls upon the aërial, their effect on the detector is to increase its resistance by raising its temperature, and thereby decrease the amount of current flowing through the telephone receiver. As long as the flow of such waves remains constant, their heating effect upon the fine platinum wire of the detector, and consequently its resistance, remains constant, and no sound is heard in the receiver. If, however, the wave-train which strikes the aërial be of a fluctuating nature, due to the vibrations of the distant telephone transmitter, the variations of amplitude of the received oscillations will cause a corresponding variation in their heating effect on the platinum wire, accompanied by like variations in its resistance, whereupon the current flowing through the telephone receiver will be similarly varied, with the result that the diaphragm is thrown into vibrations exactly imitating the movement of the transmitting diaphragm.

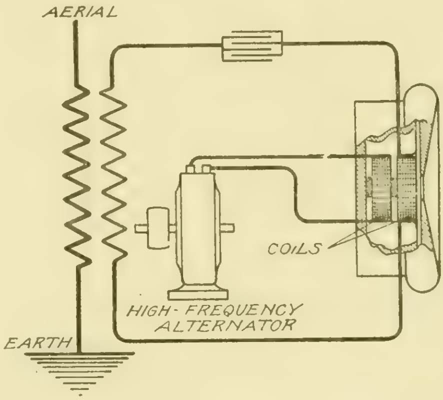


Fig. 13. **Heterodyne Receiver Circuit**

There have been previously described under the head of radiotelegraphic detectors almost all the devices used for a similar purpose in connection with radiotelephony. In view thereof it is not thought necessary to devote more space to the subject here, further than to call attention to a form of telephone receiver invented by Fessenden and called by him a "heterodyne" receiver, a most ingenious application of the Bell instrument to the purposes of space telephony. The device consists of two small coils of wire, one of which is wound upon a stationary laminated core composed of very fine soft-iron wires; the second coil, held in close proximity to, and co-axial with, the first, is attached to the center of a thin mica diaphragm. A high-frequency current from a local source is maintained through the stationary coil. The other coil, arranged to vibrate with the diaphragm, is connected in the receiving oscillation circuit, as shown in Fig. 13. The periodicity of the local alternating current is adjusted to approximately the same frequency as the received waves, thereby creating a mechanical force exerted between the two coils—a force which varies with every fluctuation of the intensity of the received oscillations, and results in vibrations of the mica diaphragm corresponding to those of the distant transmitter. When this device is used as a detector in connection with radiotelegraphy, the frequency of the local source of current is purposely made to be slightly different from the frequency of the received oscillations; under which condition the physical phenomenon known as "beats" is engendered. This is due to the fact that at certain equal intervals the two wave-form currents agree in phase and reinforce each other, while at times midway between two such successive agreements they are opposite in phase and tend to neutralize each other. These intervals of maximum reinforcement occurring at an audible frequency produce in the receiver a musical note of a duration depending upon the length of the Morse dot or dash. By means of this simple process, it is, therefore, possible to produce audible tones by the interaction of two alternating currents whose respective frequencies are far above audibility. The heterodyne receiver is almost entirely unaffected by atmospheric disturbances, and seems to offer exceptional possibilities in connection with multiplex transmission, as well as selective communication.

Two=Way Transmission. In wire telephony simultaneous talking and listening is possible by reason of the simple nature of the circuits and because of the comparatively small amount of energy involved in telephonic transmission. Radiotelephony presents in this regard difficulties which tax to the utmost present inventive ability. Without special appliances it is of course necessary after talking to throw over a listening key or switch in order to receive the reply. The introduction of this manual operation, while not of a nature to greatly detract from the usefulness of this method of communication, interferes to an appreciable extent with that ease of operation we are accustomed to associate with the telephone, and destroys the illusion of the actual presence of the person spoken to. It cannot well be expected in an art so young that minor details of this nature should have been thoroughly perfected. Arrangements for simultaneous talking and listening have already been put forward, and some have met with more or less practical success. Fessenden has patented several such devices—one involves the use of a commutator which connects the transmitter and receiver to the aërial in very rapid alternation; another and a more practicable method is called by him the "balance" method, and consists in the application of the "bridge" together with a "differential" arrangement often employed in duplex telegraphy, the complete circuit requiring a "phantom," or artificial, aërial. The detector is unresponsive to the powerful oscillations emanating from the same station, but sensitive to the oscillations from the distant station. This "balance" method materially cuts down the loudness of the received sounds.

Radiotelephonic "calling" is accomplished by radiotelegraphic methods. A coherer associated with a local battery and relay is sometimes employed to ring an electric call bell. In such cases it is necessary to provide means for cutting out the coherer and relay during conversation. Under conditions where it is impractical to achieve the operation of a relay, it becomes necessary to keep an operator on duty "listening in."

Systems of Radiotelephony. Radiotelephony undoubtedly possesses many advantages over radiotelegraphy, not the least of which is the fact that a skilled operator is not required to translate the dot-and-dash signals. The transmission of intelligence is more direct and expeditious, and in times of emergency this might become an advantage of great importance. No form of communication is so satisfying as that of speech. It is due to this fact, perhaps, that ordinary wire telephony stands today superior to the older art of telegraphy in point of development. The future may record a similarly greater development of radiotelephony than will be accorded to its companion art; but at the present time it cannot be said to compare with radiotelegraphy as regards efficiency and simplicity of apparatus. Its weak points are known and understood, however, and every effort is being made to remove the obstacles that stand in the way of a more efficient utilization of the means employed.

While still susceptible of great improvement, and in many cases requiring a multiplicity of complicated apparatus, there are a number of radiotelephonic systems which have been exploited in the various countries, many of which are in regular service. Nearly all of the large navies of the world are supplied with equipment for intercommunication between the different vessels of a fleet. Among the most successful systems may be mentioned the Telefunken and Ruhmer systems in Germany, the Poulsen system in Denmark, the Marjorana system in Italy, and in America the systems developed by Fessenden, DeForest, and Collins. Many other systems are known, but they exist in a more or less imperfect state of development.

Telefunken System. Die Gesellschaft fur Drahtlose Telegraphie of Berlin has put forward one of the most thoroughly developed systems of radiotelephony in commercial operation at the present time. It is generally known as the *Telefunken system,* which is the name applied to the radiotelegraphic system operated by the same company.

The Telefunken radiotelephonic system is of the oscillating-arc type. The arrangement of circuits is shown in Fig. 14. Six or twelve electric arcs, connected in series and shunted by an inductance and capacity, form the source of the high-frequency oscillations. The energy supplied to this portion of the circuit is derived from a direct-current source of 220 or 440 volts (if the latter, 12 arcs in series are used) connected through a rheostat, an ammeter, and a choke coil. The choke coil is used to prevent the oscillatory current from passing through the dynamo. A hot-wire ammeter is included in the oscillatory circuit, and another between the aërial and the ground,

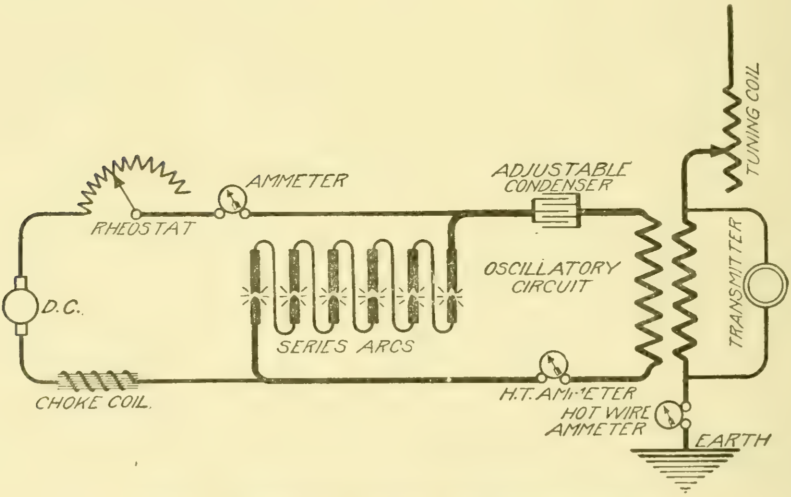


Fig. 14. Transmitter Circuit of the Telefunken System

used for tuning purposes. When the circuits are in exact resonance, these instruments give a maximum reading, thus affording a very convenient means of ascertaining if the system is in proper adjustment at any time. An adjustable condenser is provided in the oscillatory circuit, and a variable inductance in the aërial, to facilitate tuning. It will be noted that the carbon transmitter is associated with the aërial as a shunt around the secondary of the oscillation transformer. An ordinary transmitter is used and, in practice, means are provided for opening the transmitter circuit while calling, and at other times when it is desired to protect the transmitter from the detrimental effects of continued exposure to the heavy current.

The electrodes employed for the arcs in this system possess features of interest. The positive member is formed by a copper tube about 2½ inches in diameter and 8 inches long closed at the bottom by a concave piece of the same material. The internal cavity is filled with water, thus serving to keep the metal cool. Fig. 15, which shows the Telefunken electrodes, represents the positive member as partially cut away in order to make clear the construction. The negative electrode is of carbon 1½ inches in diameter, set well up in the concave portion of the positive electrode, but separated therefrom by a gap of about ⅛ inch. The arc formed between these two members tends to maintain the uniformity of the gap. It is claimed that the consumption of carbon is only about 1 inch in nearly 300 hours, and that the copper electrode is not appreciably affected by the arc. The water is changed as often as required, according to the time it is subjected to the heat of the arc, or by reason of evaporation. Means are provided for the adjustment of each individual arc, and for the simultaneous striking of all. The frequency usually achieved by this method is approximately 375,000 cycles per second. The equipments are rated something under one kilowatt for connection with 220 volts.

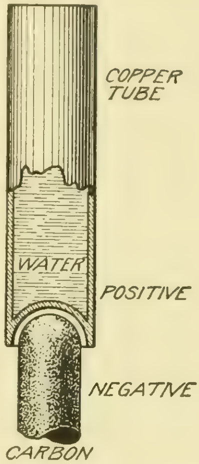


Fig. 15. Telefunken Electrodes

The receiving arrangement used with this system is of the simplest kind, consisting of a detector (electrolytic or thermo-electric) and telephone directly coupled to the aërial, such as are commonly employed with radiotelegraphy. The entire apparatus is very compact, requiring but little space, and may be conveniently placed on a small table. A distance of 25 to 45 miles may be very well covered with the Telefunken sets such as are supplied for use on shipboard, and equipments of greater power may be had. Simultaneous talking and receiving is not provided for in this system.

Ruhmer System. The system due to Ernst Ruhmer, the German investigator, well known for his extensive work in connection with the development of "light telephony" and for his researches into the properties of selenium, is characterized by the use of an oscillatory arc burning in hydrogen or other suitable gas. The Ruhmer circuits are shown in Fig. 16. A local-battery transmitter circuit is employed to superimpose, by means of an induction coil, the voice current upon the supply terminals of the oscillatory portion of the arrangement. A direct-current dynamo of 440-volt pressure is used. The transmitting aërial is inductively coupled to the closed oscillation circuit. Many different forms of arc have been experimented with by this inventor, some with a magnetic blow-out. Simplicity of apparatus has been aimed at. The receiving arrangement consists of an electrolytic detector, battery, and telephone receiver

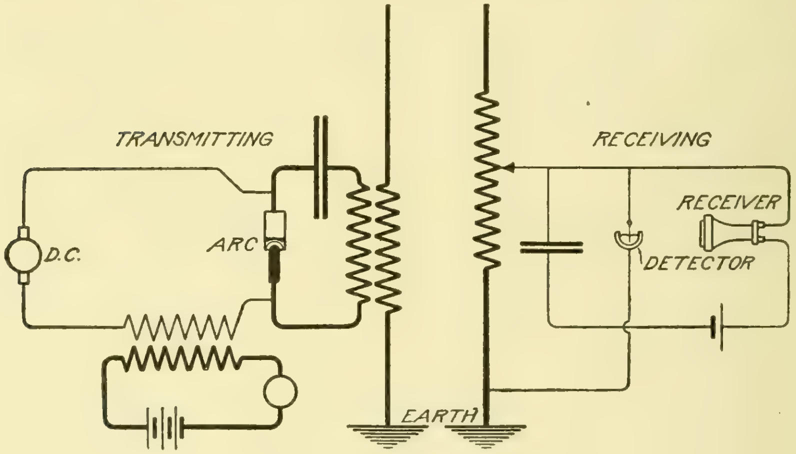
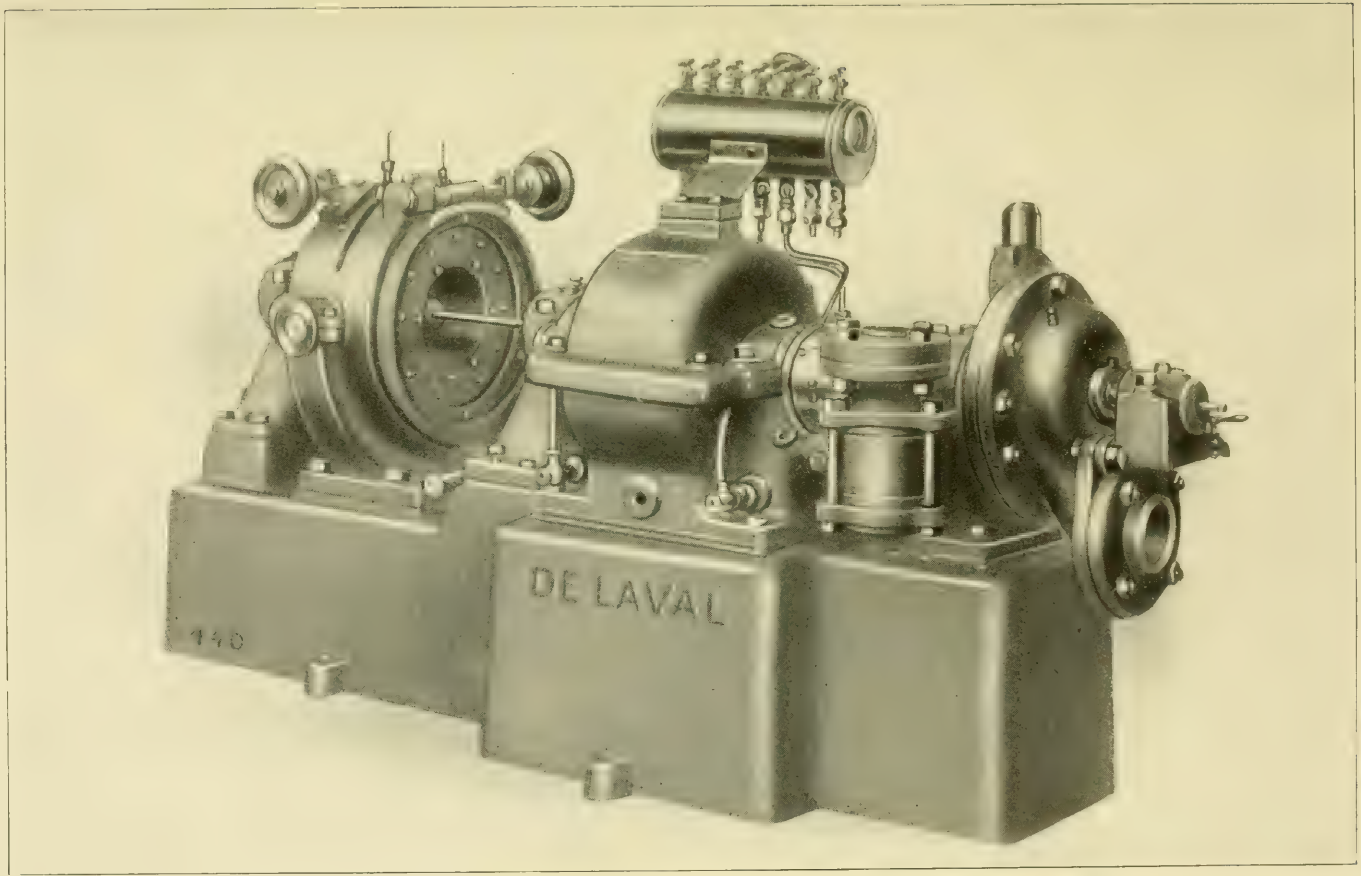


Fig. 16. Circuits of Ruhmer System



DE LAVAL "CLASS A" TURBINE DRIVING ALTERNATING-CURRENT GENERATOR FOR WIRELESS TELEGRAPHY

Courtesy of DeLaval Steam Turbine Company

connected with the aërial and its associated capacity and inductance. By using fairly low antennae, the Ruhmer system has operated very successfully over comparatively short distances.

Poulsen System. Special interest attaches to the Poulsen system by reason of the fact that the development of the arc method of producing sustained high-frequency oscillations was largely due to the initiative of this investigator. Mention was made of the Poulsen modification of the singing arc in its application to radiotelegraphy. Fig. 17 represents diagrammatically its application to a system of radiotelephony. A direct current from a suitable source is applied to the terminals of the arc through the secondary of a small transformer, in the primary of which is placed a local battery and telephone transmitter. The aërial is directly coupled, and two oil-condensers are so located as to prevent the direct current from reaching the aërial or ground. The magnetic blow-out devices are not shown in the cut. At the receiving station the aërial is inductively coupled with a closed oscillatory circuit which is connected with a local-battery circuit containing the detector and a telephone receiver.

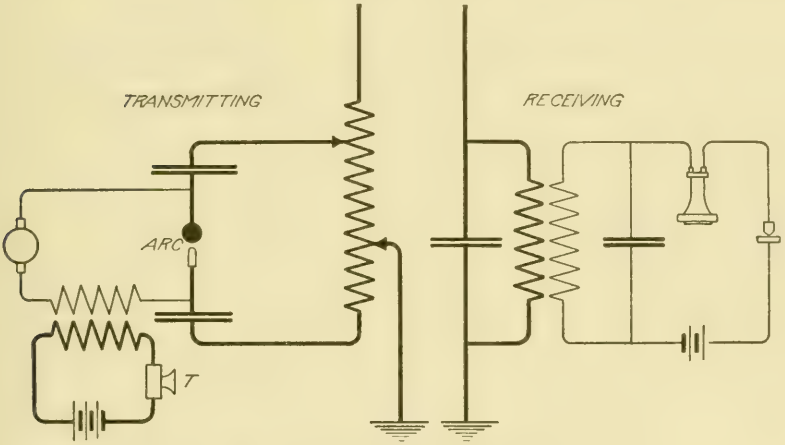


Fig. 17. Circuits of Poulsen System

Poulsen has constructed many forms of the copper-carbon arc burning in a magnetic field in an atmosphere of gas. In order to meet the difficulties caused by the irregularity of action due to the unequal burning of the carbon, he employs in connection with one form of his arc a cylindrical carbon electrode of large diameter which is slowly rotated, thus presenting constantly a new surface for the arc. In another modification, the same result is accomplished by means of a rotary magnetic field which acts directly on the arc, causing the latter to constantly change its position on the surface of the electrodes. He has also employed various gases through which the arc is maintained. In the commercial equipments more recently put out, the gas is supplied by alcohol allowed to drip slowly into the arc chamber, at a rate of about one drop every half second.

The transmitter employed by Poulsen is essentially the common carbon-granule device; he has, however, effected the variation of his oscillations by means of a multiple transmitter consisting of seven or eight such instruments connected in multiple and arranged to be acted upon by one mouthpiece.

Successful telephonic communication has been accomplished over distances varying from a few miles up to three hundred. Poulsen long-distance stations are located at Lyngby, Denmark; at Berlin, Germany; and at Cullercoats near Newcastle, England; and smaller stations are located in Denmark and elsewhere. The aërial used at Lyngby for long-distance transmission is about 225 feet high, and is of the umbrella type composed of 24 strands of phosphor-bronze wire. A 20-horse-power gasoline engine operates a 10-kilowatt, 500-volt, direct-current dynamo for the arc. A phonograph record has been transmitted from this station to Berlin and distinctly heard there—a distance of 325 miles.

The Marjorana System. In Italy radiotelephonic experiments have been carried on by Prof. Quirino Marjorana, resulting in the successful transmission of the voice from Rome to Messina, a distance of about 312 miles. As a means of creating the required oscillations, the Marjorana system employs an arc essentially identical with that used by Poulsen. The transmitting arrangement, however, is characterized by a peculiar manner of accomplishing the variations of intensity of the radiated waves. The complete circuit, including diagrammatic representation of the Marjorana liquid microphone, or transmitter, is shown in Fig. 18. The aërial is inductively coupled with the source of oscillations. The arc is fed through the blow-out magnets, which thus serve as choke coils to prevent the high-frequency current from flowing through the direct-current dynamo, which acts as supply. The receiving portion of the system possesses no points of novelty, as it is of the simple inductively coupled type and employs any of the well-known detectors suitable for this class of work.

It is the transmitter which, as suggested above, forms the distinguishing feature of this system. Its action is based upon the fact observed by Marjorana that a steady stream of water falling from an elevated containing vessel through a small orifice may have its uniformity modified by extremely minute mechanical jars imparted to the containing vessel. The liquid transmitter is designed to take advantage of this property, and is shown partially in section in the illustration. A stationary rigid containing vessel *V* terminates at its lower end in a small hole through which the water, constantly supplied to said vessel, is allowed to flow continually in the form of a minute stream. Interposed in the path of this stream is a small gap in the aërial formed by two platinum points separated a short distance. The stream completes the connection across this gap. Means, in the form of a thin diaphragm introduced as a portion of the wall of the containing vessel, are provided to affect the diameter and contour of the stream in accordance with the vibrations of the voice. The center of this diaphragm is connected by a light rod to the center of another diaphragm which is acted upon by the

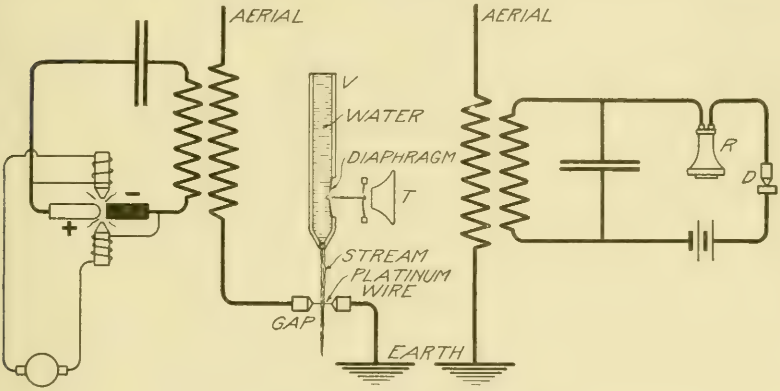


Fig. 18. Circuits of Marjorana System

voice through suitable mouthpiece. The action is as follows: The vibrations of the double diaphragm are communicated to the volume of the liquid in the form of variations of pressure manifested at the orifice and resulting in similar variations in the volume of water constituting the stream. Such modifications of the stream produce, at its juncture with the platinum electrodes of the aërial, corresponding variations in the resistance of the gap. It is of course obvious that this action produces corresponding variations in the intensity of the radiations. Numerous fluids and electrolytes have been employed by Marjorana in place of water. A form of ionized gas detector has been used in connection with this system with excellent results.

Fessenden System. In reviewing the development of radiotelephony it has been necessary to refer so often to the work of Fessenden relative to the many innovations introduced into the art by him that little remains to be said in this place in regard to the complete system which bears his name. The bibliography of radiotelephony includes many papers and articles by Fessenden of the greatest interest to the student of wireless communication. A remarkably clear and concise paper on the subject of wireless telephony, replete with much valuable data on transmission, etc., was presented by Prof. Fessenden at the 25th annual convention of the American Institute of Electrical Engineers at Atlantic City in June, 1908. Many illustrations and descriptions of the apparatus employed by him were given.

Among the many interesting facts determined by Fessenden in his very exhaustive tests dealing with the atmospheric absorption of electric waves, may be mentioned the fact that waves of a comparatively low frequency suffer less absorption than those of a much higher frequency, both being of equal power. Messages were successfully transmitted in daylight with a wave-frequency of 80,000 per second from Brant Rock, Massachusetts, to a radiotelegraphic station in the West Indies—a distance of 1,700 miles—with comparatively little absorption; while at the higher frequency of 200,000 per second communication was impossible.

The power required for radiotelephony, Fessenden states to be about five to fifteen times that required for radiotelegraphy. Fessenden has employed at various times all the well-known methods of generating a sustained train of waves but has met with greater success, particularly in radiotelephony, by the use of some form of the high-frequency alternator method, shown in Figs. 6, 7, and 12, used in connection with the heterodyne receiver illustrated in Fig. 13.

The Fessenden system has transmitted speech from Brant Rock to New York City with an expenditure of about 200 watts. Longer distances have also been covered with higher power apparatus. Fessenden's patents are controlled by the National Electric Signaling Company.

DeForest System. This system is exploited by the Radiotelephone Company and is due to Dr. Lee DeForest. It is an oscillating arc system presenting nothing of special novelty. Fig. 19 shows the essential features of the operating circuits, though in practice a more convenient means is provided for facilitating the change from the transmitter to receiver. The arc is of the Poulsen type, taking place between a copper positive electrode, water cooled, and a carbon negative. An electromagnetic means is provided for automatically adjusting the length of the arc by a movement of the carbon through the agency of a solenoid, which is represented in the drawing by the turns of wire around the left-hand electrode. A variable resistance is employed to effect the proper regulation of this feature. The arc is made to burn in the flame of a small alcohol lamp. The aërial is inductively coupled to the closed oscillation circuit, the latter containing two condensers connected in multiple,

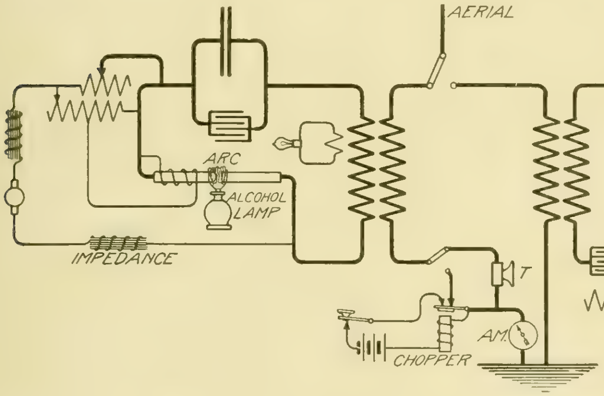


Fig. 19. Operating Circuits of the DeForest System

one of which is adjustable for tuning purposes. A small incandescent lamp, connected to a closed circuit, is placed in inductive relation with the primary of the oscillation transformer in order to give a visual indication of the proper working of the oscillation arc. The transformer used for inductive coupling with the aërial is of compact flat spiral design, the primary and secondary being placed side by side in a loose inductive couple. For telegraphic and "calling" purposes, a device for rapidly interrupting the steady flow of waves, called a "chopper," is thrown in by the movement of a switch; whereupon it becomes possible, by the operation of the Morse key, to cut up the wave-train into any desired combination of dots and dashes. The telephone transmitter, which is introduced between the aërial and the ground, is out of circuit during such a performance. A hot-wire ammeter is placed in the aërial circuit to indicate when the latter is in tune. For the detector, a form of the DeForest audion receptor is used, connected in the circuit as shown.

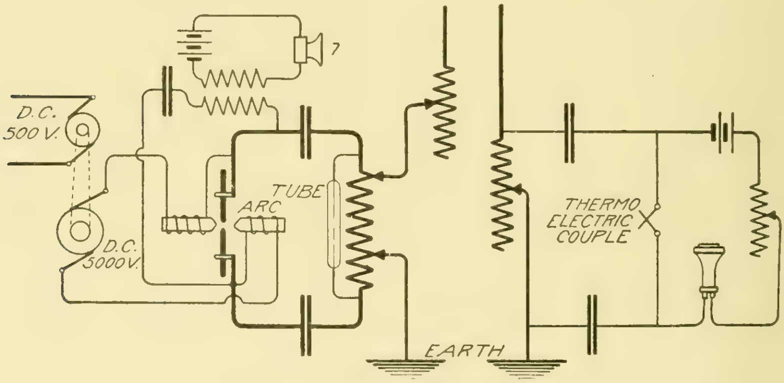


Fig. 20. Circuits of the Collins System

The DeForest system has met with considerable success, and has been installed on several United States battleships. Tests have been made with the DeForest equipment by the British Admiralty, and the greatest distance over which it was possible to transmit satisfactorily was about 57 miles, a distance which has since been extended with improved apparatus. The sound from phonographic records transmitted by this system when temporarily installed at the Eiffel Tower in Paris, was said to be audible 400 miles away. This station permitted of the use of an exceedingly tall aërial, the tower being nearly 1,000 feet high.

Collins System. This system has been developed by A. F. Collins, who for several years has carried on experiments in the field of radiotelephony. The circuits employed are shown in Fig. 20, the arrangement including some unusual features though nothing in the nature of a radical departure. The oscillations are created by an arc of a higher potential than is generally used, 5,000 volts being supplied through the agency of a direct-current dynamo directly coupled to a 500-volt motor. The electrodes of the arc are both in the form of carbon disks, which are made to revolve by means of a small motor, as shown in Fig. 21. A magnetic blowout is also provided, the coils of which serve the purpose of choke-coils, thus preventing the oscillatory current from entering the generator. The aërial is of the direct-coupled type in both the transmitting and receiving stations. A visual indication of the correct working of the arc takes place in the form of a glow within an exhausted glass tube. This tube is supplied with platinum terminal wires sealed into the ends, and projecting inwardly to within a short distance from each other. This device is shunted across the inductance in the closed oscillatory circuit. The transmitter is located in a local-battery circuit and acts inductively on a shunt connected across the terminals of the arc. This shunt includes the secondary of the induction coil and a condenser. Collins has recently employed several transmitters connected in multiple and operable through a common mouthpiece. The detector employed in this system is the invention of Collins, and is in effect a sensitive thermo-electric couple composed of two dissimilar metals, the juncture of which is heated by the received oscillations. The variation of this thermal effect produces a corresponding variation in the effective resistance of the detector, and consequent vibrations of the receiver diaphragm

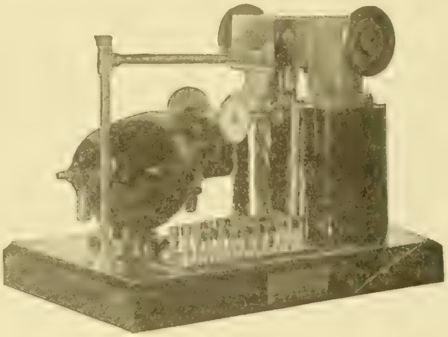


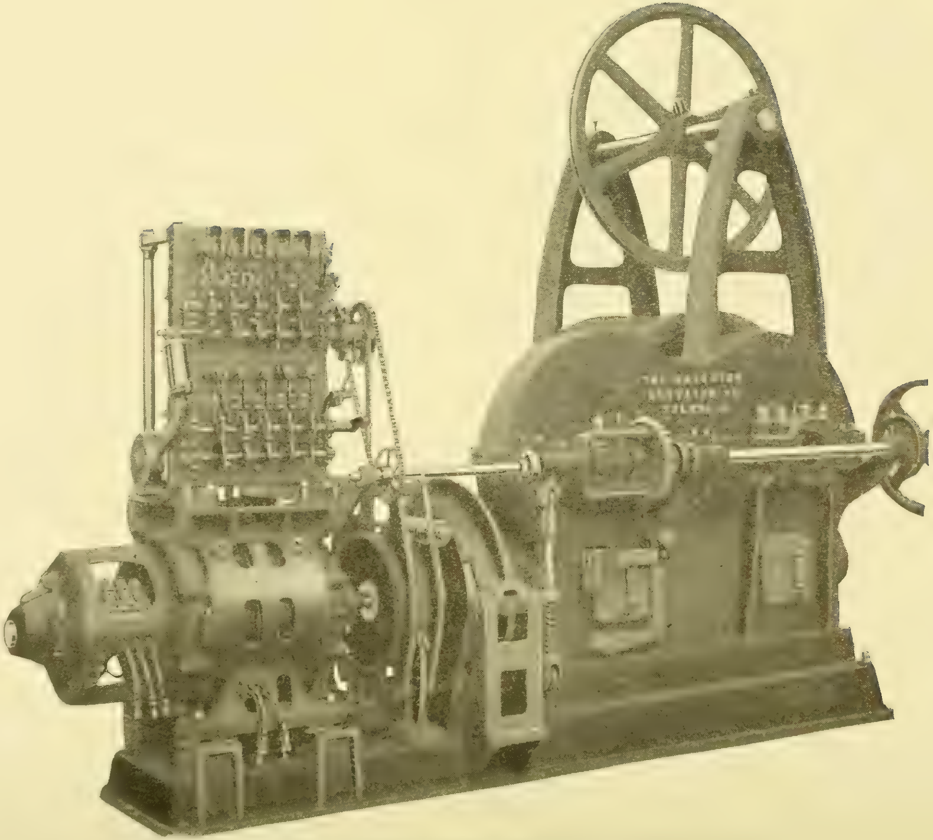
Fig. 21. Collins Revolving Electrodes

The Collins system is exploited by the Collins Wireless Telephone Company of Newark, New Jersey.

Conclusion. In conclusion attention is called to an important characteristic of radiotelephonic communication which has been observed in practice, namely, the exceptional clearness of articulation, due to an absence of wave-form distortion which is always present in wire telephony by reason of the deleterious effect of the electrostatic capacity of metallic lines and cables. This fact alone bespeaks wonderful promise for this form of telephony, particularly in view of the very limited distance over which it is at present possible to telephone when the medium is a submarine cable.

Experience has thus far shown that great advantage is to be gained by the very accurate tuning of the various circuits in connection with radiotelephony as well as with radiotelegraphy. The employment of sustained oscillations greatly facilitates the accomplishment of more perfect resonance; which, in turn, tends to eliminate interference and aids selective communication. Experience has also shown that in systems using an inductively coupled aërial, a decided gain in the clearness of articulation is noticeable when such coupling is "loose." In practice, therefore, the primary and secondary helices are often separated several inches.

In the foregoing discussion of radiotelephony it has been impossible to do more than very briefly present the subject. Many interesting questions of a theoretical nature and a description of several other systems, it has been found necessary to omit. If, however, the present short survey awakens a greater interest in space-communication, the reader may avail himself of the extensive literature dealing with the subject, and delve as deeply into the theory and problems involved as he desires.



TANDEM GEAR DOUBLE BRAKE ELEVATOR ENGINE WITH VARIABLE SPEED CONTROL

Courtesy of Haughton Elevator and Machine Company

ELEVATORS

PART III

ELECTRIC ELEVATORS

Early Types. The first application of electricity as a motive power for elevator service was made in the year 1889, and was doubtless suggested by its successful use on street cars and in driving lines of shafting in industrial establishments. The installation consisted of an ordinary shunt-wound motor belted to a countershaft, which in turn drove a two-belted worm-geared hoisting apparatus. The starting, stopping, and reversing movements of the cage, or platform, were obtained theough the medium of an operating cable by means of which the open or cross belt was shifted as desired from the loose pulley to the driving pulley of the hoisting machine or *vice versa;* a brake was applied automatically with the cable at stopping position.

In this type of machine, the motor had to be started and allowed to attain normal speed before the elevator could be put into service and, furthermore, the motor had to run continuously even when the elevator was being loaded or unloaded. This arrangement was very wasteful of electric current and the speed was limited.

Various attempts were made to overcome these difficulties, and in many cases the methods used were unique and proved impractical. One of these, the Pratt-Sprague, consisted of a long screw running horizontally in bearings at either end, which were driven directly by a motor placed at one end. The screw ran in a nut having a cross head, which traveled horizontally on guides, the same as the cross head of a horizontal hydraulic elevator, and was supplied with sheaves on either end. The construction of the machine was such that a double set of traveling sheaves and also fixed sheaves were necessary. The cables were rove over these sheaves like any horizontal hydraulic, and the motor was reversible.

One of the principal features of this type of machine was the construction of the nut which traveled on this large screw. It was supplied with steel balls on the "pull" side of the screw, and these ran close together in single file through a channel, which carried them around through the threads of the nut and caused them to return to the other end of the same after they had passed through. Of course, there had to be so many of them that they completely filled the channel from one end to the other, and it was thought that their use would reduce the friction to a minimum. It was found, however, in practice that flat spots were soon worn on them and they ceased revolving, thus cutting grooves or scores in the thread of the screw—a very serious matter. Elevators of this type were also very prone to become deranged, and their operation was not as economical as had been anticipated.

The controlling device was quite novel and the operation of the cage very agreeable and pleasant. The control of the motor driving this screw was effected by means of a small pilot motor, which in turn was operated by means of push buttons in the cage. Very few, if any, of these elevators are in use at the present time.

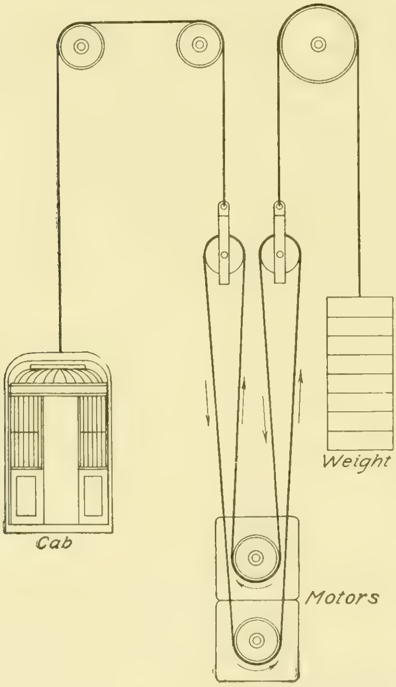


Fig. 121. Diagram of Fraser Elevator Driving Mechanism

Another type was the Fraser elevator, the driving mechanism of which consisted of two motors set one above the other. These motors were necessarily of the slow speed type, running about 420 r. p. m., and each one had upon the armature shaft sheaves of about 20 inches diameter. Cables were arranged so as to form a double bight or loop around each of these pulleys on the armature shafts, as in Fig. 121. The cables ran from these sheaves over two pulleys, one attached to the car cable, and the other to the counterpoise cable. The motors ran in opposite directions, and by means of rheostats placed in the cab the fields were weakened or strengthened, in order to vary the speeds of the motors. Referring to the diagram it may be seen that when both motors were running at the same speed, no motion of the car would result; but by varying the speed of either motor, the car would run at a speed equal to half the difference in speed of the two motors. No motor reversing apparatus was needed, the motion of the car being obtained entirely by the change in speed; this gave a most desirable method of making stops and starts. The machine was very severe on the cables, so destructive in fact that they had to be frequently renewed; and taking it altogether, the design was not found so desirable as had been anticipated, from the standpoint either of economy or maintenance. However, actual results in operation were all that could be desired, including the speed attained and smoothness of stops and starts.

Difficulties with Variable Speeds. In the latter part of 1889, the first attempt was made to run elevators by means of the motor attached directly to the worm shaft. Two elevators built on this principle were installed in buildings on Broadway, New York City, but they were not eminently successful, owing to their inability to start under a full load and to difficulties experienced with the controllers.

It was soon discovered that a motor which was entirely shunt-wound did not have sufficient torque to start the load unless a motor enormously large for the work was used, thus entailing an additional expense which did not seem warranted. A trial of a series winding in addition to the regular shunt winding was found to solve the problem satisfactorily as far as starting was concerned, but the use of the compound motor caused the elevator to have a variable speed depending upon the load lifted. This speed variation interfered seriously with the stopping of the cage exactly at the different landings, even when the stops were made automatic by means of a striker attached to the cage, an arrangement which was quite popular and in general use at that time.

To remedy this defect the controller was so constructed as to cut out the series winding as soon as the motor had attained its normal speed, leaving it to run on the shunt winding only. This arrangement produced the desired results, viz, a normal and regular car speed under all loads and consequently perfect control in stopping the car at the various landings. The details of the method by which this has been accomplished will be fully described under the heading "Control".

These difficulties overcome, the electric elevator became a real competitor of the older and better known hydraulic types.

MOTOR DESIGN

Requirements. The motor requirements for elevator service differ materially from those for almost any other kind of work and the duties performed are, with possibly one or two exceptions, the most exacting.

In most lines of work the motor is started running light, and the load is applied after the normal speed has been attained. The elevator motor, however, must not only be able to start under full load, but it must pick up, or attain, its proper speed under that load and do it within a period of from four to eight seconds. After normal speed has been acquired, the speed must remain unchanged until the circuit is broken for the purpose of stopping.

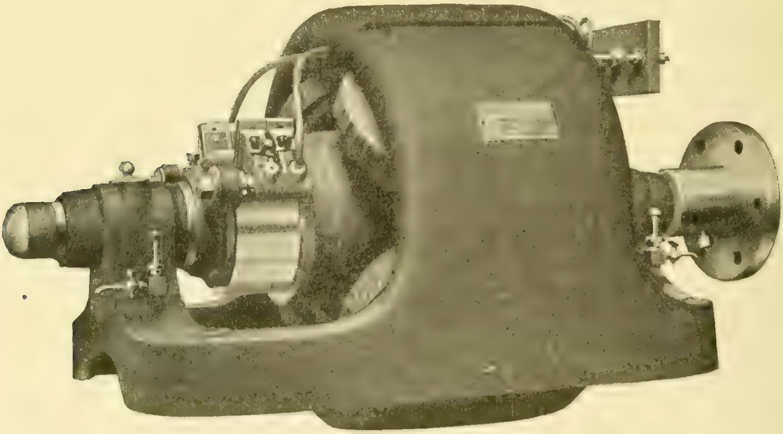


Fig. 122. Direct-Current Elevator Motor
Courtesy of Warner Elevator Manufacturing Company

Direct-Current Motors Most Suitable. To any one conversant with the subject, it will be apparent that a special design is absolutely essential for this particular service. With an alternating-current motor, only an approximate fulfillment of the requirements is possible; but with a direct-current motor, the degree of perfection is indeed gratifying when compared with the service obtained only a few years ago. Some of the special features of the direct-current motor designed for this work are as follows: low speed; high starting torque; massive frame, Fig. 122, and field cores; ample shunt windings fully up to the full power of the motor; series windings equal to at least 50 per cent of the horsepower of the motor, these to be in sections so they may be cut out gradually as the motor picks up speed, and to consist of wire almost, if not quite, as large in carrying capacity as the service wires; brushes of sufficient carrying capacity and with an ample area of commutator contact; and rigid brush holders that will not jump or clatter when the motor is running.

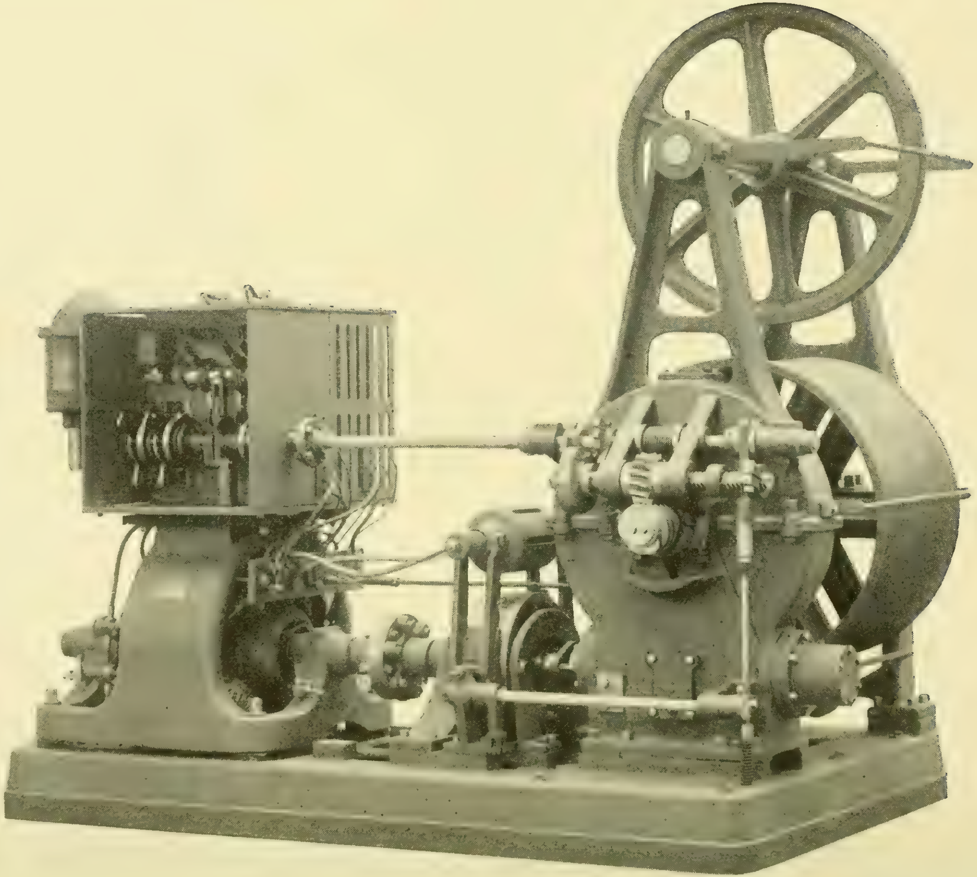
High Cost Inevitable. A motor built on the lines just suggested and operated by a well-designed controller will give very satisfactory service and will last for years if kept properly cleaned and lubricated. This last condition is seldom met, for, generally speaking, elevator motors do not receive the attention they should have. Furthermore, the motors are not always of a design suitable for the work expected of them, and it has taken an enormous amount of urging, of argument, and of pleading on the part of the elevator maker to get the motor builder to recognize the peculiar needs of this kind of service. The motor manufacturer is not altogether to blame for this, for frequently the keen competition met with in securing desirable contracts has tempted the elevator builder to use an inferior motor—a practice which has invariably led to trouble. All attempts to produce a less expensive motor which would at the same time give the proper service have failed. Today the features enumerated above are fully recognized by all the best and most reliable motor makers as being absolutely essential to a serviceable and long lived motor for this kind of work.

Faults in Design. *Light Shafts.* One of the mistakes which designers often make is the result of early practice in connection with belted transmission. In these early forms, where the pulley of the motor was much smaller than the driven pulley and the motor started before the load was applied, the low starting torque allowed of a much lighter armature shaft than would be necessary when the motor started under full load. As a result of the change to direct-connected design and to the practice of picking up under load, many instances of shafts twisting off under the heavy starting torque bear witness as to imperfect design or to an attempt to skimp material.

Heating of Motors. Again, motor designers in many cases reasoned that because a motor in this kind of service ran intermittently, it did not have time to heat to a dangerous extent before it was stopped, and during the interval before starting again it would cool. With this fallacious deduction as a basis, they built every part of the machine of light weight for the sake of economy in production, with the result that the motor was heated to a very unsafe degree in its efforts to start under load and the insulation around the copper wires comprising the windings of both armature and field was ultimately destroyed. The rewinding of these coils is an expensive operation and, of course, the loss of efficiency of the motor during the transition from perfect insulation to an actual short circuit in the coils is a more insidious and baffling process.

This brief description clearly explains the absolute necessity of having motors ample in power and of proper design, with liberal windings, field cores, and frame. Another practice which resulted in bad heating was that of keeping the field windings of the bipolar motors excited all of the time in order to produce a fairly prompt start. This resulted frequently in incipient fires and even where this did not occur it brought about the premature destruction of the field windings. Today, in all cities where regulations are in force to insure proper installation of electric elevator equipments, the current must be entirely cut off from the motor when the elevator is stopped, a regulation which has proved as beneficial to the elevator maker as to the owner of the plant. Furthermore, bipolar motors have been entirely discarded for this service by the best makers as they have been found less efficient than other types, especially in starting under load.

Slow Speed. It used to be contended that a slow speed motor was not so efficient as those of higher speed, but as the question of design has been more thoroughly investigated and understood, these objections have all been overcome. In fact, such a degree of perfection in the design of motors for elevator service has been attained that within the last few years motors running efficiently at a speed as low as 40 r. p. m. are frequently met with in connection with the so-called gearless type of elevator engine.



LARGE THIRTY-HORSEPOWER, HIGH-SPEED, FULL ELECTRIC CONTROL PASSENGER ELEVATOR ENGINE

Courtesy of Warner Elevator Manufacturing Company

MODERN TYPES

Interpole Motors. For variable speed elevators a type called the "Interpolar Motor" is now in general use. This motor, as its name would indicate, is a direct-current motor with additional poles and field windings interposed between the regular fields, making it an 8-pole motor, Fig. 123. The interpoles are provided with series windings, the wire used being as large in cross section as the line which feeds the motor and consisting of one continuous wire, one end of which is connected with the line and the other end with one of the armature leads. Current flowing in these windings energizes the interpoles, thus making them alternately north and south poles, or the reverse, according to the direction of the current passing through them.

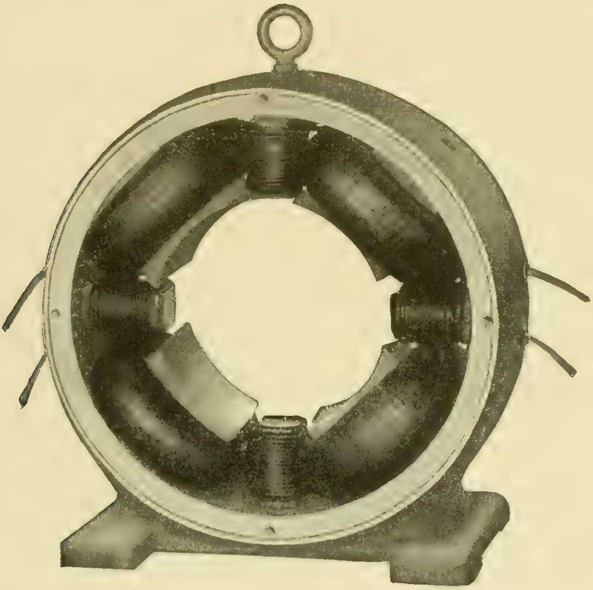


Fig. 123. Interpole Motor Field Ring and Coil
Courtesy of Electro-Dynamic Company

The regular fields of the motor are wound both series and shunt, as shown on page 165. When the motor is started, the current flows through these heavy series windings and gives the motor abnormally heavy fields at the slow speed, thus enabling it to start under as heavy a load as it will be called upon to carry at full speed. The weakening of these abnormally heavy fields by decreasing the current in the interpole windings and cutting out the series windings on the regular fields increases the speed of the motor to double its starting speed. This, of course, is done through the agency of the controller in one, two, or three steps, thus giving the motor two or three speeds as may be desired. These speeds are about 375 r. p. m. to start with, and 950 r. p. m. for full speed.

In high speed elevators running at 350 to 400 f. p. m. at maximum, this is a valuable feature in a motor because it enables the operator to start and pick up speed gradually, the acceleration occurring during a period of time covering only a few seconds. These results may be obtained either through the medium of the operating switch or by an automatically operating device attached to the controller.

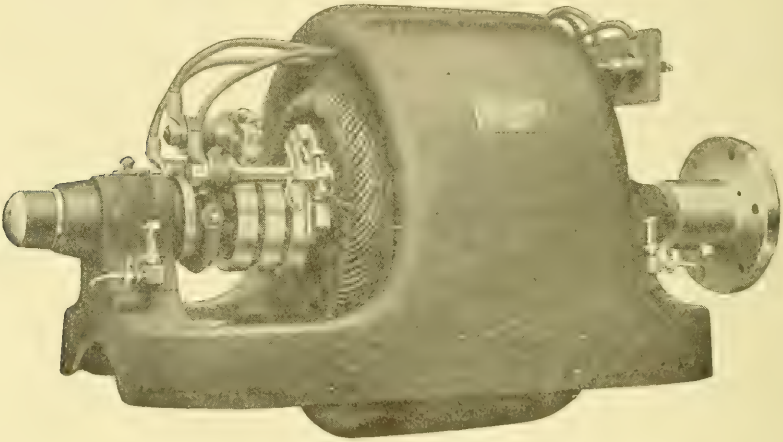


Fig. 124. Alternating-Current Type of Elevator Motor
Courtesy of Warner Elevator Manufacturing Company

Alternating-Current Motors. With motors built to run on alternating current, Fig. 124, none of the features described are obtainable, the motor being simply started and allowed to attain its normal speed if the elevator is unloaded, or its nearest approximate when loaded. The variation between the synchronal and full load speeds is from 5 to 10 per cent, the alternating-current motor resembling to some extent the compound-wound direct-current motor in this respect. The greatest difficulty experienced with motors of the alternating-current type is their lack of ability to start under a heavy load, and for this reason proportionately larger sizes must be used, the increase in horsepower required being fully 33 per cent. This increased size of the motor is really an advantage, for, besides giving a heavier torque at starting, it furnishes an excess of power which enables the motor to run at full speed without such noticeable fluctuations with changes in load as would be the case with a smaller motor.

CONTROL

Functions of Control. Starting, accelerating, slowing down, stopping, and holding the elevator securely at the various landings are governed by the *control*, which is, therefore, a very important part of the operating mechanism of the electric elevator.

Starting. In starting, the brake is released and simultaneously the current is admitted to the motor. With direct-current motors, however, the full strength of the current may not be admitted until the motor has attained nearly its full speed. The current is controlled by passing it through resistance coils or through cast-iron grids made from iron of a known degree of purity and density. These coils or grids, which are arranged in sections, or *banks* as they are technically termed, are introduced into the circuit when the current is first admitted to the motor and by their resistance tend to cut the current down to a limit that is safe for momentary admission to the motor windings without endangering the insulation.

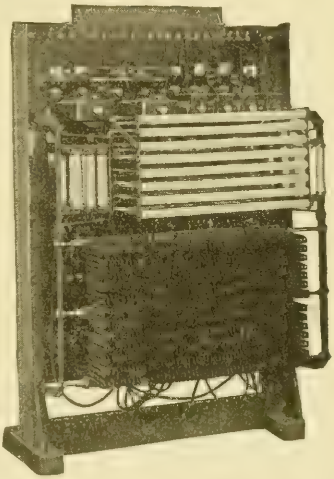


Fig. 125. Back View of Control Board
Courtesy of Otis Elevator Company

Acceleration. The moment the armature starts to revolve, the strength of the current flowing through it may be slightly increased without danger. As the strength of the current increases so does the speed of the armature, and with each increase of speed other sections of resistance are successively cut out of the circuit until the armature has attained nearly its normal speed. At this time the current is allowed to pass directly from the line into the armature, thus giving it the acceleration necessary for its full power and normal speed.

TYPES OF CONTROLLERS

Functions. A controller differs from the ordinary motor starter in that it performs several other functions besides that of simply starting the motor. It controls the energizing or cutting out of the circuit of the solenoid which operates the brake; it reverses the direction of rotation of the armature as desired; it controls the resistance in the field circuit, thus giving increased speed when needed; in the case of the interpolar motor previously described, it cuts in or out the series windings for the purpose of controlling the power of the motor to start up under load; finally, by introducing resistance into the armature circuit, a dynamic brake power is generated for use in slowing down the elevator and when lowering very heavy loads.

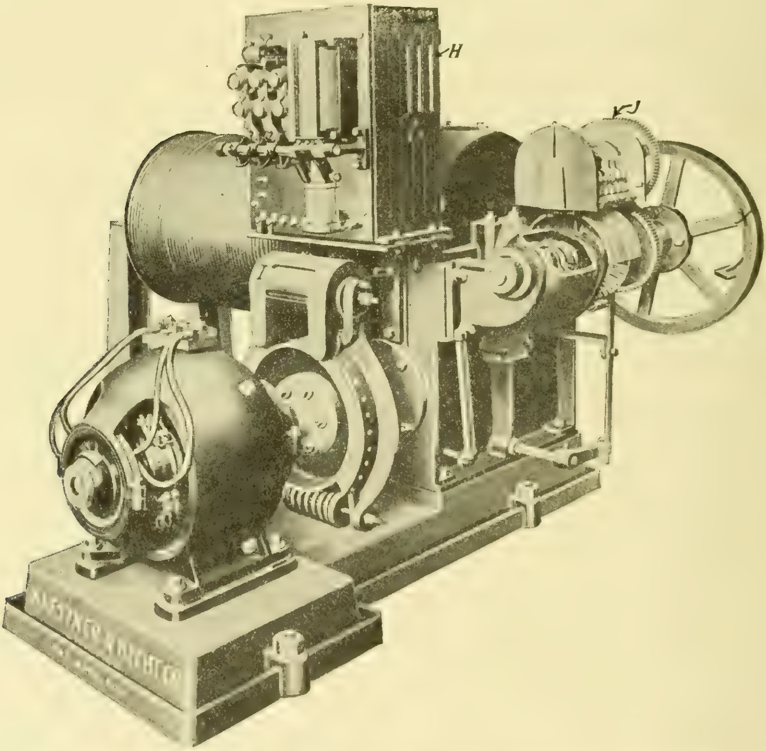


Fig. 126. Freight and Passenger Elevator for Direct Current Operated by Lever or Hand Cable
Courtesy of Kaestner and Hecht Company

The controller as usually arranged consists of banks of resistance mounted on one side of a marble or slate slab, Fig. 125, on the opposite side of which are arranged the various solenoids and switches by means of which the different operations above described are carried out. This slate or marble slab is held upright by a suitable iron frame and holes are drilled for the passage of various wires and for the bolts used in attaching the parts to the slab. Marble makes the best switchboard material on account of its perfect insulating qualities, although slate is equally as good if free from streaks of metal, the presence of which will prove fatal to perfect insulation.

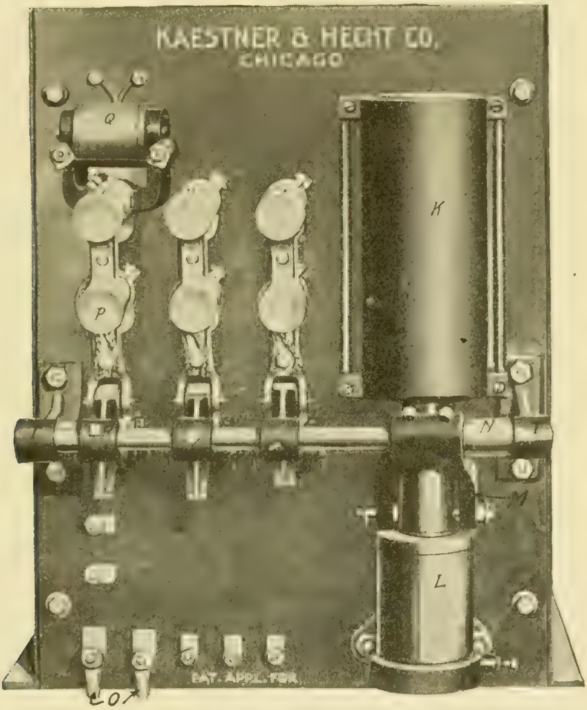


Fig. 127. Direct-Current Semi-Magnet Controller for Hand Cable and Lever Control Operation
Courtesy of Kaestner and Hecht Company

Direct-Current Controller. *Controller Proper.* A good example of the more simple direct-current type of controller is shown at *H* in Fig. 126, and in Fig. 127, which gives a front view on a larger scale, with the various solenoids and switches mounted in position. Referring to Fig. 127, *K* is the main solenoid, the energizing of which causes the plunger to rise and pull up the lever *M*, causing the shaft *N* to make a partial revolution; the cams *R* which are attached to the shaft *N* are, by its rotation, made to close the switches *P* consecutively (the cams being adjusted in proper position to do this), and, as each switch closes, it cuts out one bank of resistance and thus accelerates the car. The amount of time for accomplishing this is regulated by the dashpot *L*, a short tube filled with oil, containing a piston attached to the lower end of the solenoid plunger. By allowing the oil above the piston to escape through a graduated opening to the lower end of the cylinder, the upward motion of the plunger is retarded at will. The time required to close the three switches is from four to six seconds, depending on the nature of the work being performed by the engine. The moment the circuit is broken or opened for stopping, the plunger is quickly restored to its original position by means of a quick-opening valve working in one direction which allows the oil to return to its place above the piston. *Q* is a

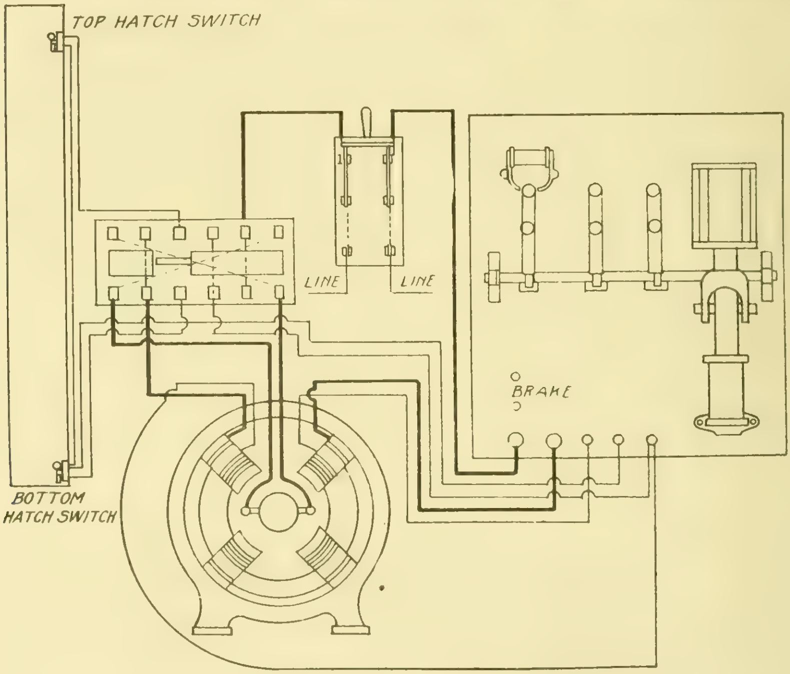


Fig. 128. Wiring Diagram for Semi-Automatic Controller for Compound-Wound Dynamo
Courtesy of Kaestner and Hecht Company

magnet, the office of which is to blow out the arc caused by opening the last switch.

In order that the student may get a better idea of the circuits necessary to allow the controller to perform its functions, a few typical wiring diagrams will be introduced. Fig. 128 is a diagram of a semi-automatic controller for a compound-wound motor.

Starting and Stopping Switch. The opening and closing of the circuit for starting and stopping the motor are accomplished by means of the starting switch *J*, Fig. 126. This switch, which is of the rotating make-and-break type, is connected to the operating sheave by means of a pair of spur gears, and when the switch is made to revolve by means of the operating cable (which is passed around and attached to it), this closes the circuit in the direction it is desired that the elevator shall run. This controller performs but two functions: (1) cutting out the resistance in order to increase the current and bring about the proper speed; and (2) releasing the brake by energizing the solenoid *I*, Fig. 126, which pulls together the upper ends of the brake shoes, neutralizing the effect of the powerful spring connecting their lower ends, Fig. 129. Hence, the brake is applied at all times except when the solenoid *I* is energized. The wisdom of this arrangement is seen in case of accident or failure of the electric current, for the brake is then automatically set.

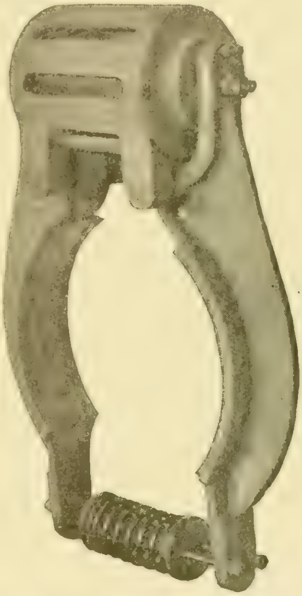


Fig. 129. Brake Shoe Operated by Solenoid

Alternating-Current Controller. *Mechanically-Operated Type.* When an alternating current is used for operating the elevator, different types of motor and controller are necessary. Only two- and three-phase motors have been found applicable to this problem, as no successful reversing alternating-current motor of the single-phase type has yet been made. As to the controller, the use of the solenoid on alternating-current circuits is not in general favor owing to the expense of production and its noisiness in operation. In these cases, therefore, the makers have resorted to mechanical means for operating the brake and switches on the controller, while the cheaper and slower types are operated by hand cable or lever device at the car.

An electric engine of this type, Fig. 130, corresponds in every respect to that shown in Fig. 126, except that the brake *1* and controller *2*, also shown in Fig. 131, are mechanically operated and the motor is of the alternating-current type.

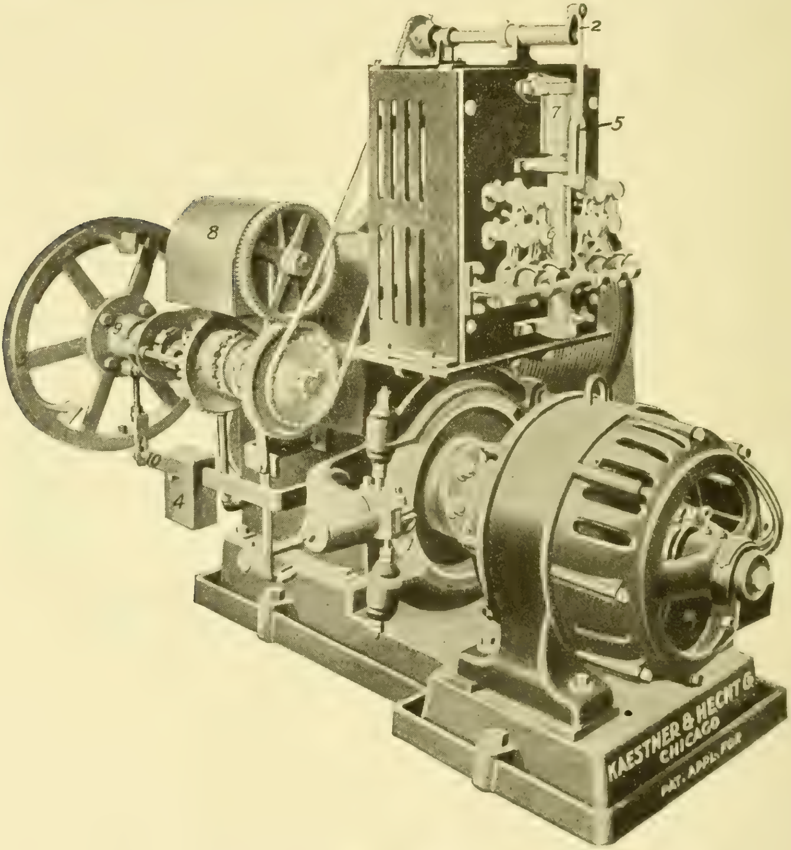


Fig. 130. Freight and Passenger Machine for Alternating Current
Courtesy of Kaestner and Hecht Company

To operate the controller, one-quarter revolution of the operating sheave *3* causes the crank *2* to make one-half revolution, the ratio between the sprocket wheel on the end of operating shaft and that on shaft at top of controller being two to one. When the crank

2 makes one-half revolution in either direction, the pitman *5* goes with it, leaving the plunger *6* free to descend by gravity. The motion of this plunger is retarded by the action of the dashpot *7*, in precisely the same manner as that for Fig. 127. The action of this plunger in dropping is practically the same as in the electrically-operated type, causing a shaft to revolve partially and, through the medium of cams, to close switches and thus cut out resistance from the motor. The making, breaking, and reversing of the circuit is done by the switch *8*. When the operating sheave is revolved in either direction to start the elevator, a cam at *9* lifts the brake lever *10*, thus

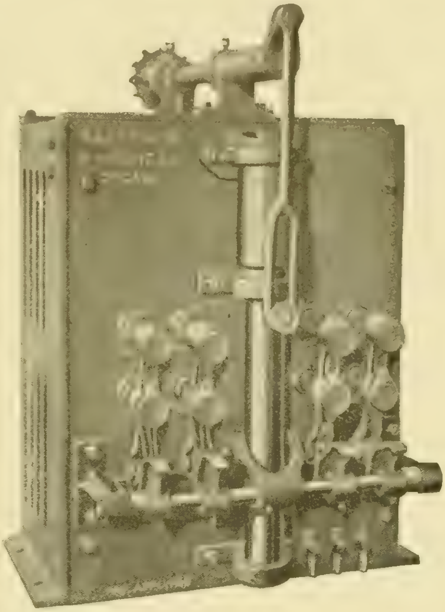


Fig. 131. Alternating-Current Mechanical Controller

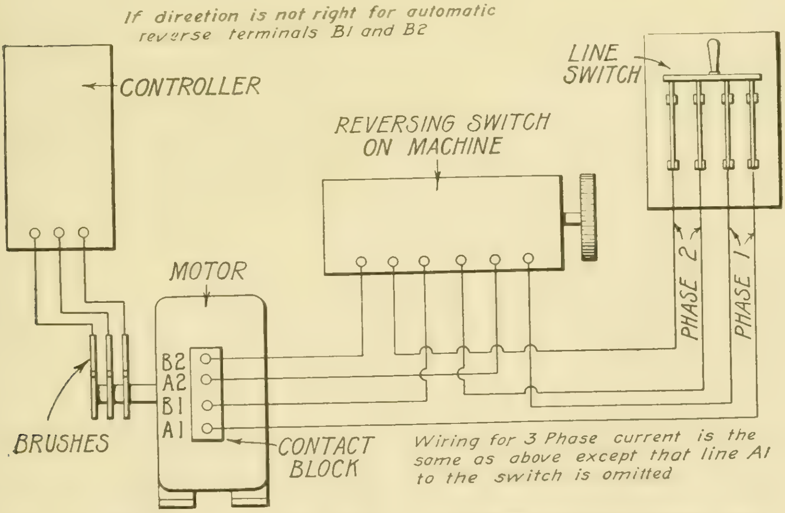

If direetion is not right for automatic reverse terminals B1 and B2
CONTROLLER
LINE SWITCH
REVERSING SWITCH ON MACHINE
MOTOR
PHASE 2
PHASE 1
B2
A2
B1
A1
BRUSHES
CONTACT BLOCK
Wiring for 3 Phase current is the same as above except that line A1 to the switch is omitted

Fig. 132. Wiring Diagram for Two-Phase or Three-Phase Elevator Equipment with Mechanical Control

releasing the brake; and when the operating sheave *3* is returned to its original position, it drops the brake lever, and the weight *4* applies the brake by gravity.

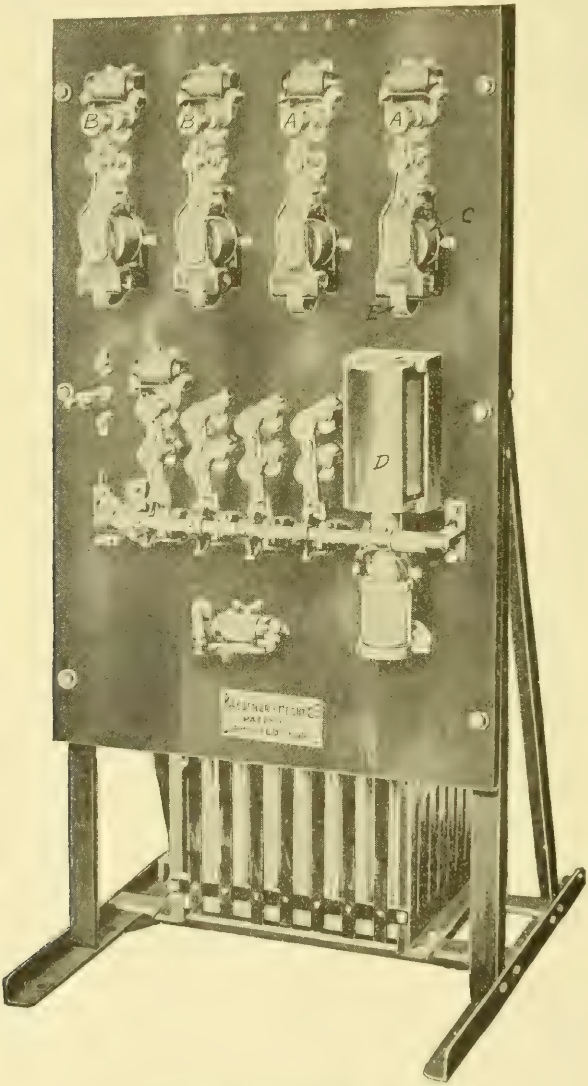


Fig. 133. Single-Speed Full Magnet Controller
Courtesy of Kaestner and Hecht Company

The wiring diagram, Fig. 132, shows the circuits for a two- or three-phase motor with mechanical control.

Magnet Control. When the motion of the car is governed by electrical means, the switches on the controller which open and close the circuit to the motor, are operated by means of electromagnets; hence the term "full magnet control". Fig. 133 is a good example of this kind of control where the mechanical operation remains unchanged. *AA* are the switches used in closing the circuit for the *up* movement of the elevator, *BB* perform the same office for the opposite direction, and *D* is the solenoid for cutting out the several banks of resistance as the motion of the motor accelerates. The line

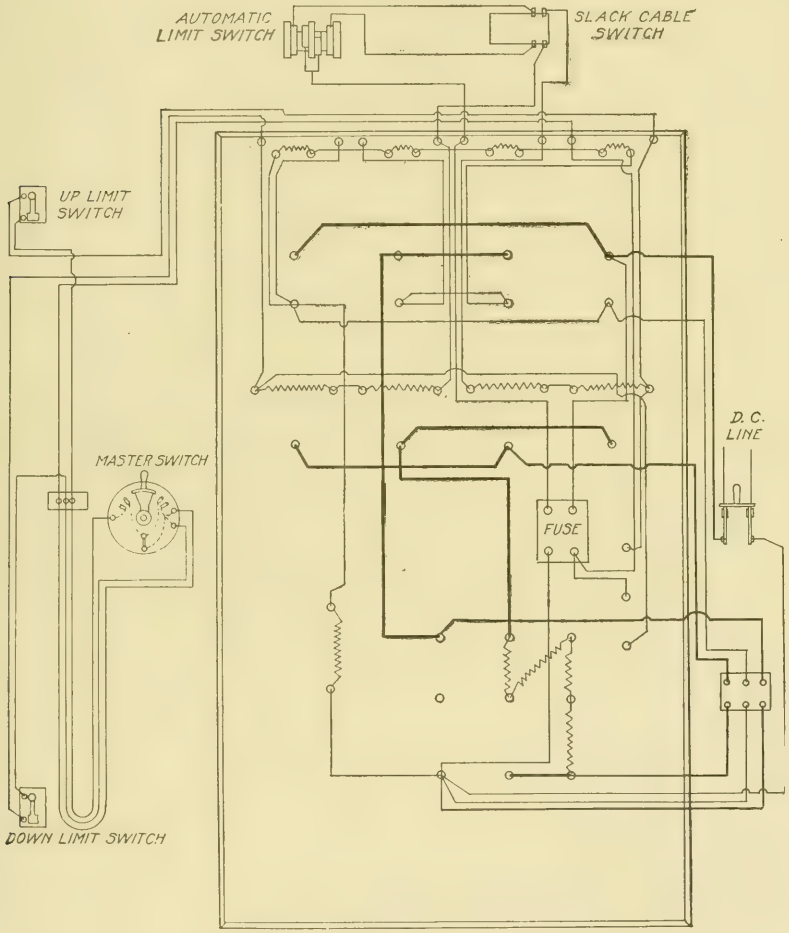


Fig. 134. Wiring Diagram of Single-Speed Full Magnet Controller

switches are closed by means of the electromagnets C, the springs E automatically opening the switches when the current in C is cut off. The wiring diagram for a single-speed full magnet controller is given in Fig. 134. Fig. 135 shows the method used by another manufacturer to accomplish the same purpose. Where a variable speed is desired, a controller, Fig. 136, similar to Fig. 133, is used; the only difference is in the use of the extra solenoid, shown at the lower left-hand corner of the board, and the accompanying switches for cutting resistance into the motor fields for accelerating the speed. This solenoid is energized by the movements of the car switch and is entirely under the control of the operator. The wiring diagram for a two-speed full magnet controller is given in Fig. 137.

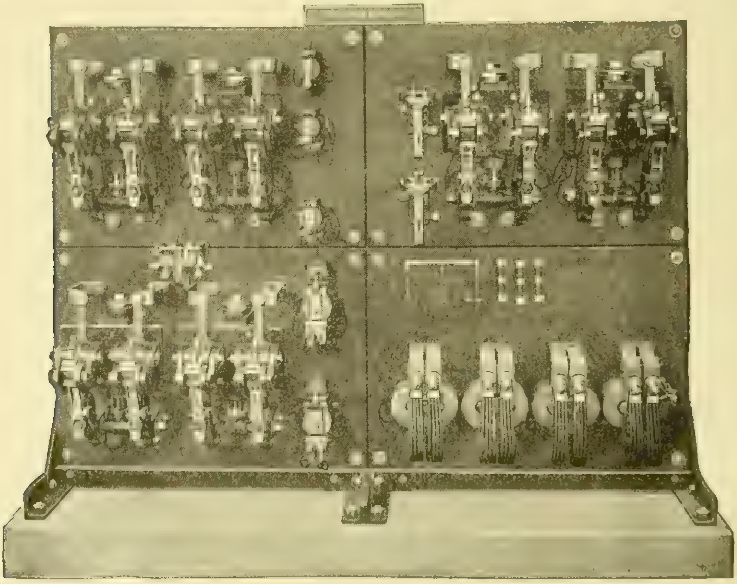


Fig. 135. Full Automatic Skip Hoist Controller for Alternating Current
Courtesy of Otis Elevator Company

Some elevator makers use a similar solenoid and switches on freight elevators, connecting the solenoid with the armature of the motor through special resistances so arranged that with light loads the solenoid is not energized, but under heavy loads the e. m. f. in the armature becomes great enough to move the plunger in the solenoid, which then operates the switches. In such cases, however, the action of the solenoid is different, as the operation of the switches cuts out resistance from the fields, thus causing the motor to run at a

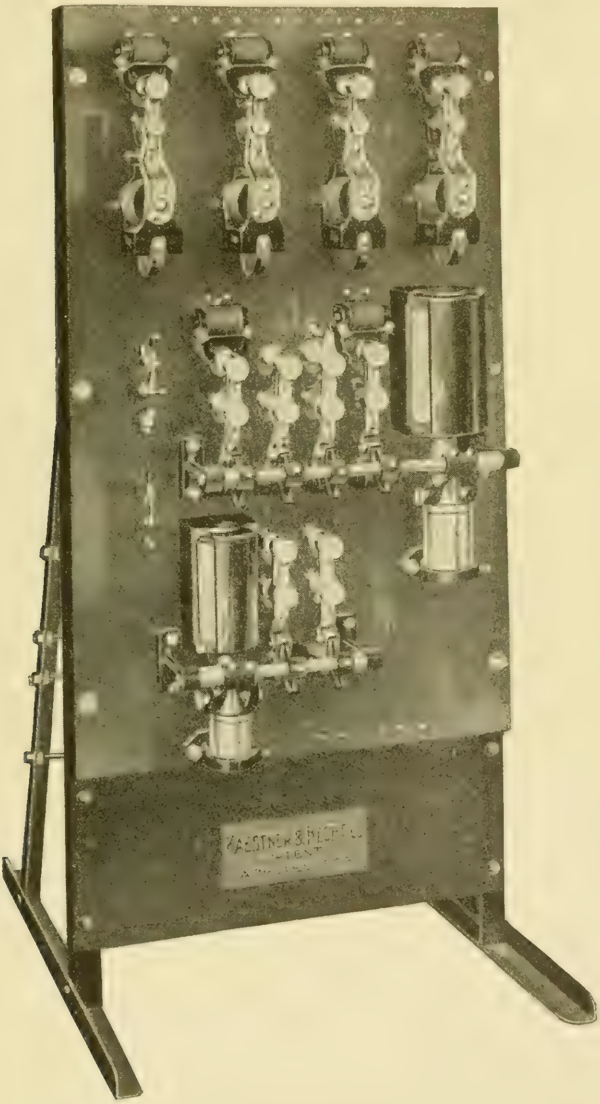


Fig. 136. Variable-Speed Full Magnet Controller
Courtesy of Kaestner and Hecht Company

slower speed—the field resistance is always in, except when the solenoid is energized. The effect of this arrangement is to produce a fairly high speed with comparatively light loads; while with a heavily loaded car, the speed is automatically lowered by cutting out the field resistance.

Fig. 138 is similar to Fig. 136, except for two sets of switches for controlling field resistance, as well as a separate switch (the center one, top row) for controlling the brake. This controller gives three speeds and is designed for use with motors equipped with interpole fields and heavy series winding, the action of which was described on page 169. Fig. 139 shows the wiring diagram for a three-speed full

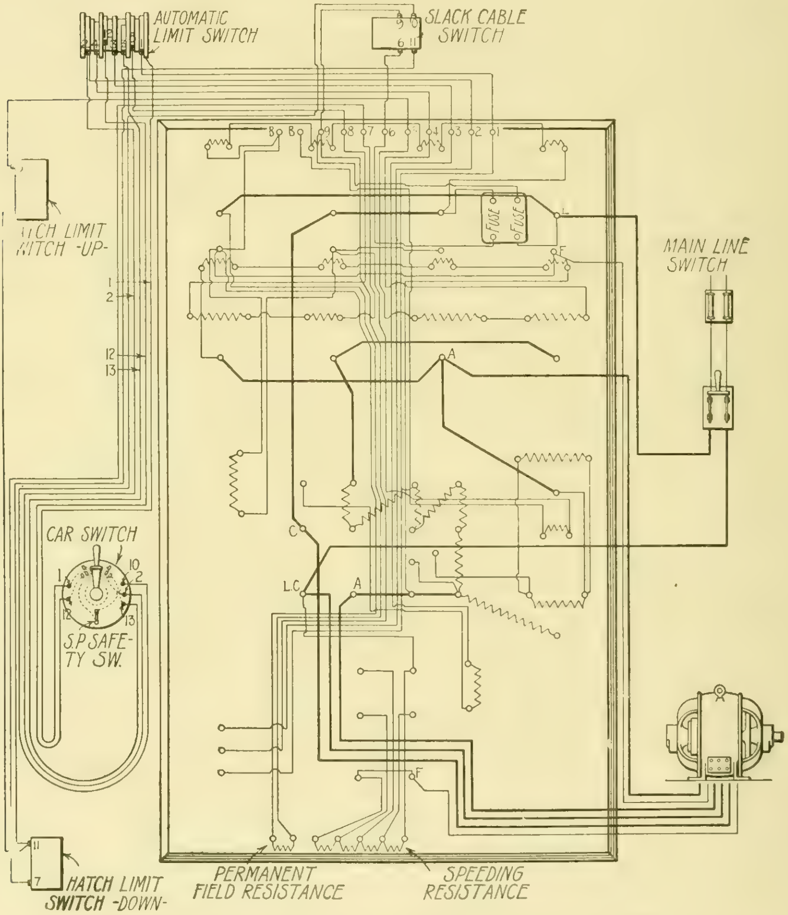


Fig. 137. Wiring Diagram of Two-Speed Full Magnet Controller

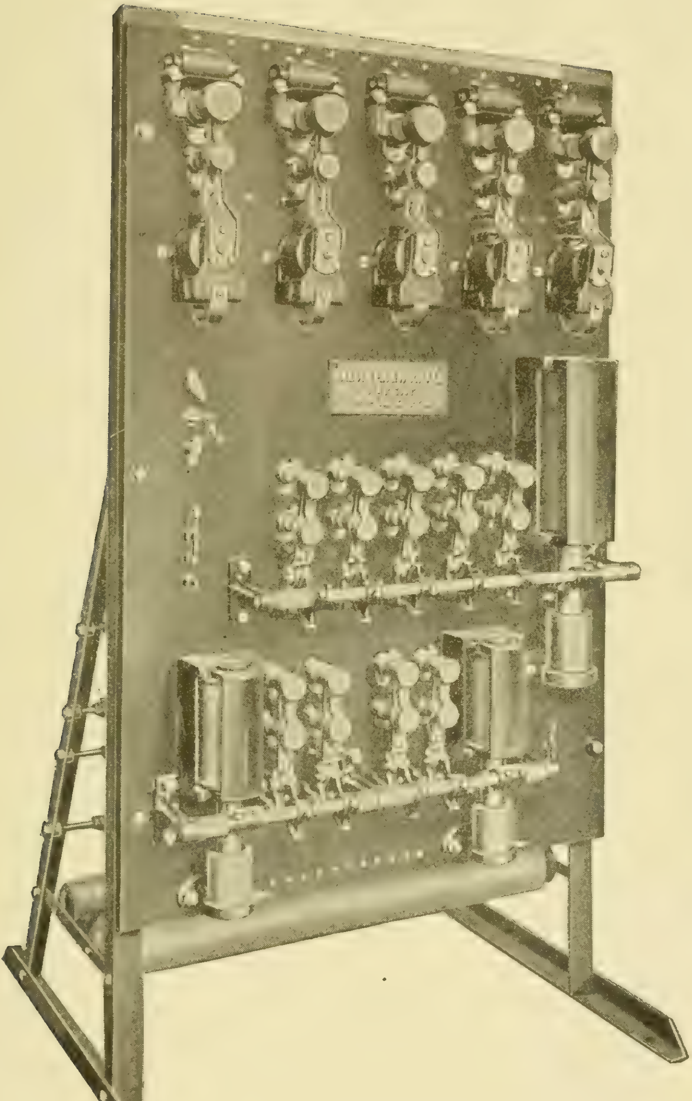


Fig. 138. Three-Speed Full Magnet Controller for High-Speed Passenger Elevator
Courtesy of Kaestner and Hecht Company

magnet controller with interlocking magnet and an extra line switch for 500 volts direct current.

Push-Button Control. MANIPULATION. Elevators using push-

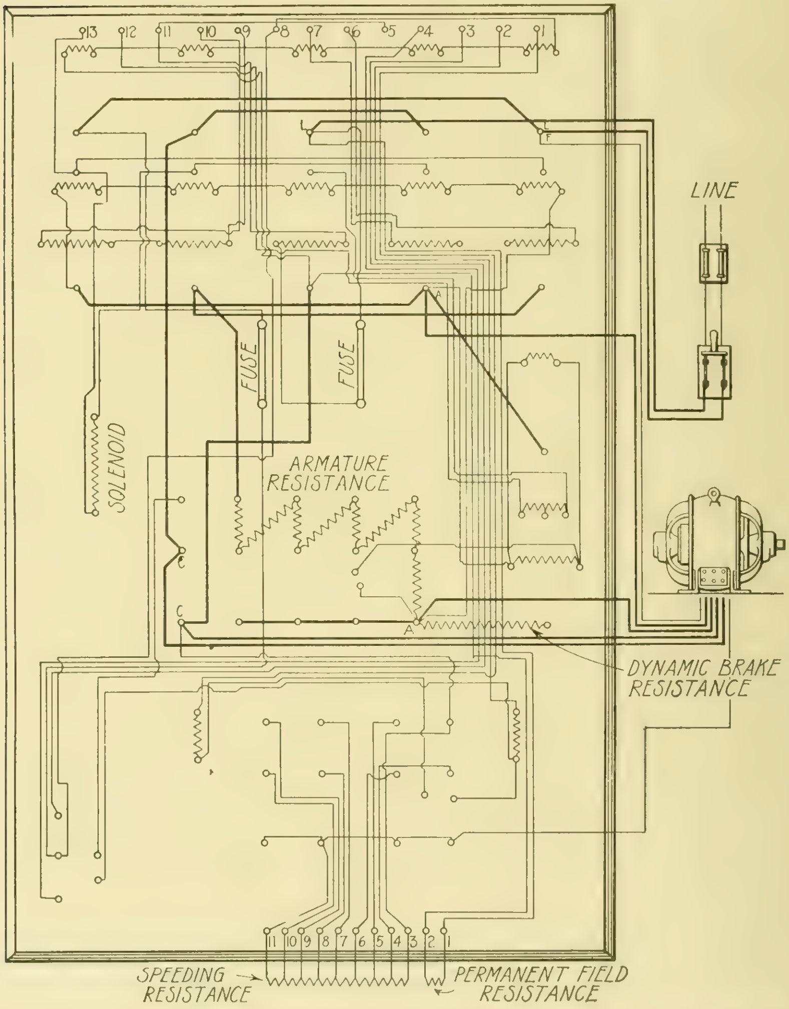
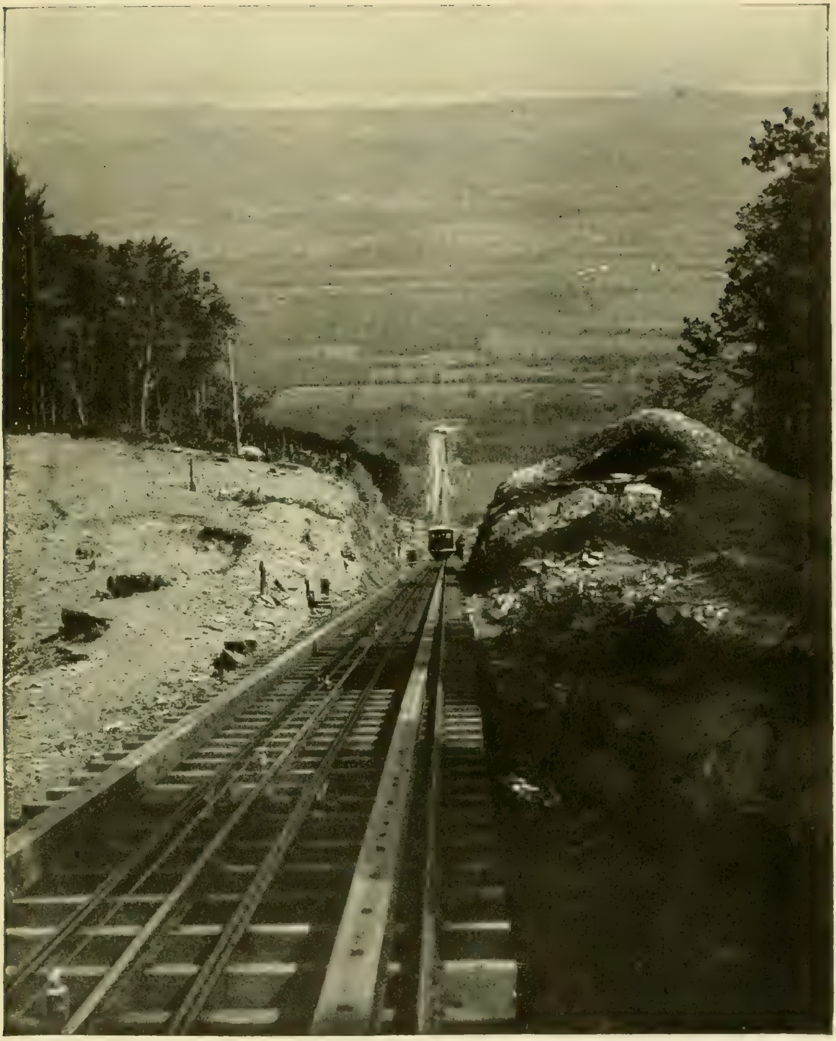


Fig. 139. Wiring Diagram of Three-Speed Full Magnet Controller with Interlocking Magnet and Extra Line Switch

Courtesy of Kaestner and Hecht Company

button controls are largely used in hospitals, apartment houses, and private dwellings. They are necessarily one-speed elevators and are intended to be operated by the passengers themselves. In Fig.



VIEW OF THE CATSKILL MOUNTAIN INCLINE RAILWAY

The total length of the road is 7000 feet, with an average grade of 23 per cent. The road is of the three-rail type and as usual in this type of railway the two cars are attached to the same cable and form a partially balanced system. Safety devices are provided in case the cable breaks.

Courtesy of Otis Elevator Company

140 is shown a controller in its usual position near the engine; Figs. 141 and 142 show wiring diagrams for a.c. and d.c. current.

The manipulation of the automatic push-button elevator may be clearly understood from Fig. 143. The person desiring to use the elevator presses a push button near the elevator door (marked "Call Button"). The elevator at once comes to the floor at which the operator is waiting and stops there. The door may now be opened, and after stepping inside the cab and closing the door, the operator selects from a bank of buttons inside the cab the one marked with the number of the desired floor and, upon pressing this button, the elevator moves to the floor designated and stops there. These push buttons are arranged one above another in a metal box, Fig. 144, and

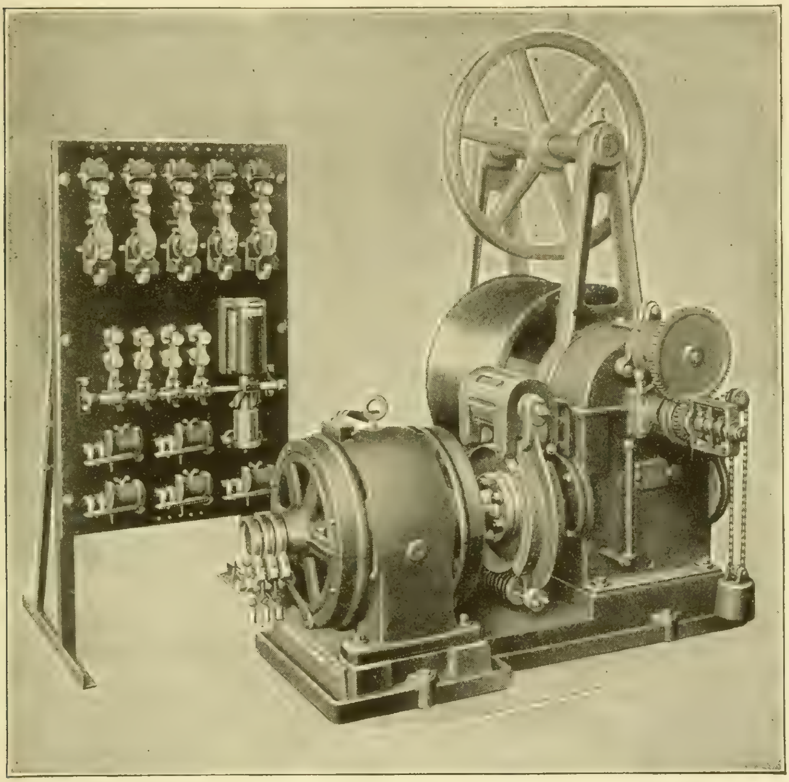


Fig. 140. Automatic Push-Button Controller and Machine
Courtesy of Kaestner and Hecht Company

are connected by means of a flexible cable with the necessary wires which run in the proper conduits to the hatch switches and to the controller.

Safety Doors. The doors to the shaft are so arranged that opening one of them breaks the circuit; consequently, if upon leaving the elevator at any floor the user fails to close the door after him, the elevator is out of service for the time being and cannot be started again until that door is closed. To prevent opening the elevator door when the car is not at the landing, a lock is provided which is released only when the car itself reaches the landing; this is accomplished by having a small cam on the car, which closes a switch, thus actuating a small electromagnet and unlocking the door. The

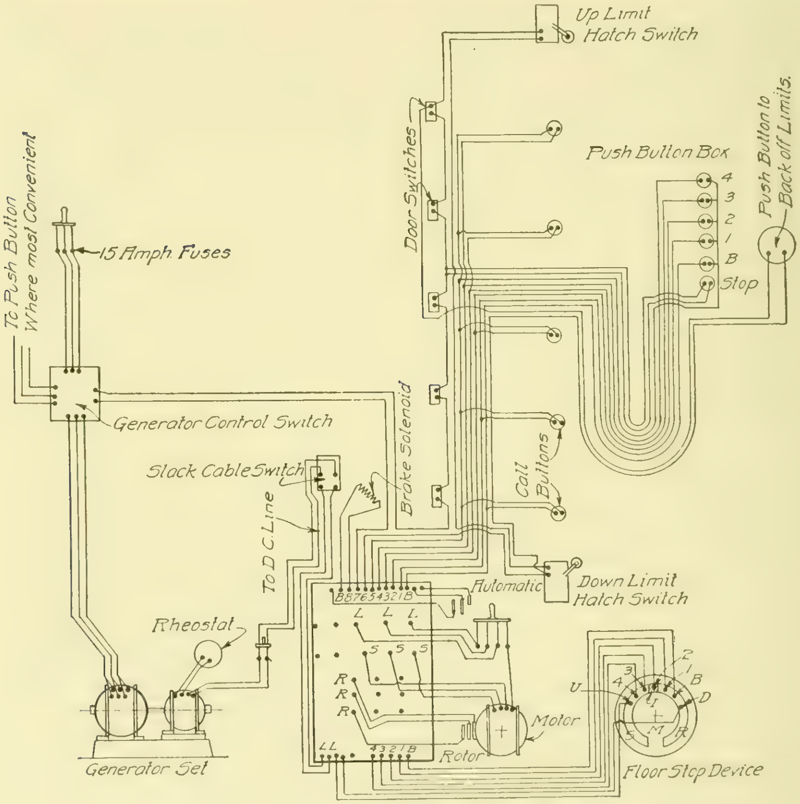


Fig. 141. Wiring Diagram of Five-Floor Automatic Push-Button Control for Three-Phase Motor
Courtesy of Kaestner and Hecht Company

circuits for this arrangement are shown in Fig. 143 and are given with sufficient clearness to be almost self-explanatory. The floor

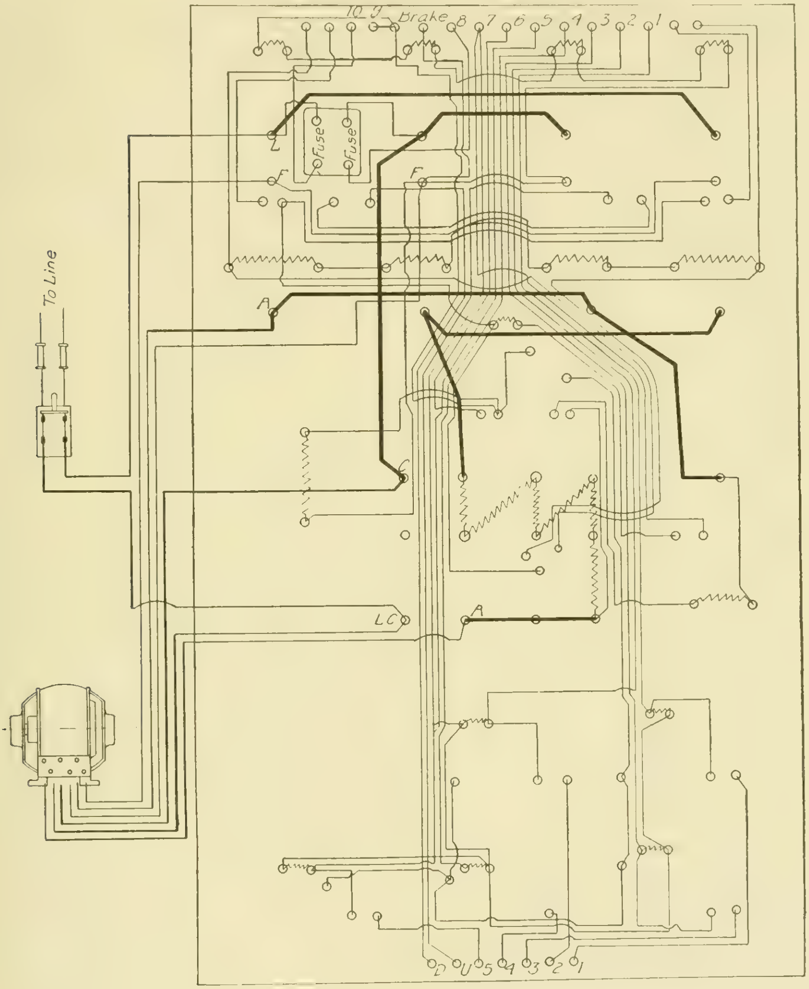


Fig. 142. Wiring Diagram of Five-Floor Automatic Push-Button Controller for D. C. Motor
Courtesy of Kaestner and Hecht Company

call buttons are on the right and the circuits leading to the car controller are clearly shown.

Up and Down Control. The up and down control of the push-button elevator, the wiring diagram of which is shown in Fig.

141, is accomplished by means of a floor-stop device as shown in the diagram. This device consists of an insulated disk *M* on which are mounted two brass annular segments *R* and *S* insulated from each other at *I* by a segment of insulating material. In front of the disk is a fixed frame containing brushes *D, B, 1, 2, 3, 4,* and *U*. These brushes are insulated from the frame and bear upon the annular segments of the disk as shown. The brush *D* is connected to the solenoid on the control panel operating the switches for a "down" direction of motion of the cage, while the brush *U* is connected to the solenoid operating the switches for an "up" direction of motion of the cage. The segment *R* may hence be called the "down" segment and the segment *S* the "up" segment in that they connect, respectively, with the switches for those particular directions of running.

The brushes *B, 1, 2, 3,* and *4* correspond to floors and each is connected to a small electromagnetic switch shown at the bottom of the panel in Fig. 140, one electromagnetic switch being provided for each brush.

Fig. 141 is drawn on the assumption that the car is at rest at the second floor, in which case brush *2* is on the insulated segment *I*. Assume now that the fourth-floor call button or the fourth-floor button in the car is pressed. The momentary pressing of the button will operate the corresponding electromagnetic switch for that floor at the bottom of the panel. The switch will complete the circuit of the solenoids operating the main switches for an upward movement of the cage, through the brush *4*, the "up" segment *S*, and the brush *U*. The car will hence move upwards. In so doing the disk *M* will be caused to revolve in a counterclockwise direction, as it is connected to the cable drum or a cable sheave by means of a chain and sprocket wheels which give the disk a motion proportional to the motion of the cage and a direction of motion dependent upon the motion of the cage.

Hence the rotation of the disk *M* will cause the insulated segment *I* to move to the left. It will then pass under the brush *3*, and after its passage the brush *3* will bear on the "down" segment *R*, but the car will continue to move upwards, as the "up" switches were closed through brush *4*. When brush *4* bears on the segment *I*, it, of necessity, ceases to bear on the "up" segment *S*, and hence the circuit to the "up" switch solenoid and the brake-release solenoid is broken and the car stops. Now the disk is so geared to the cable

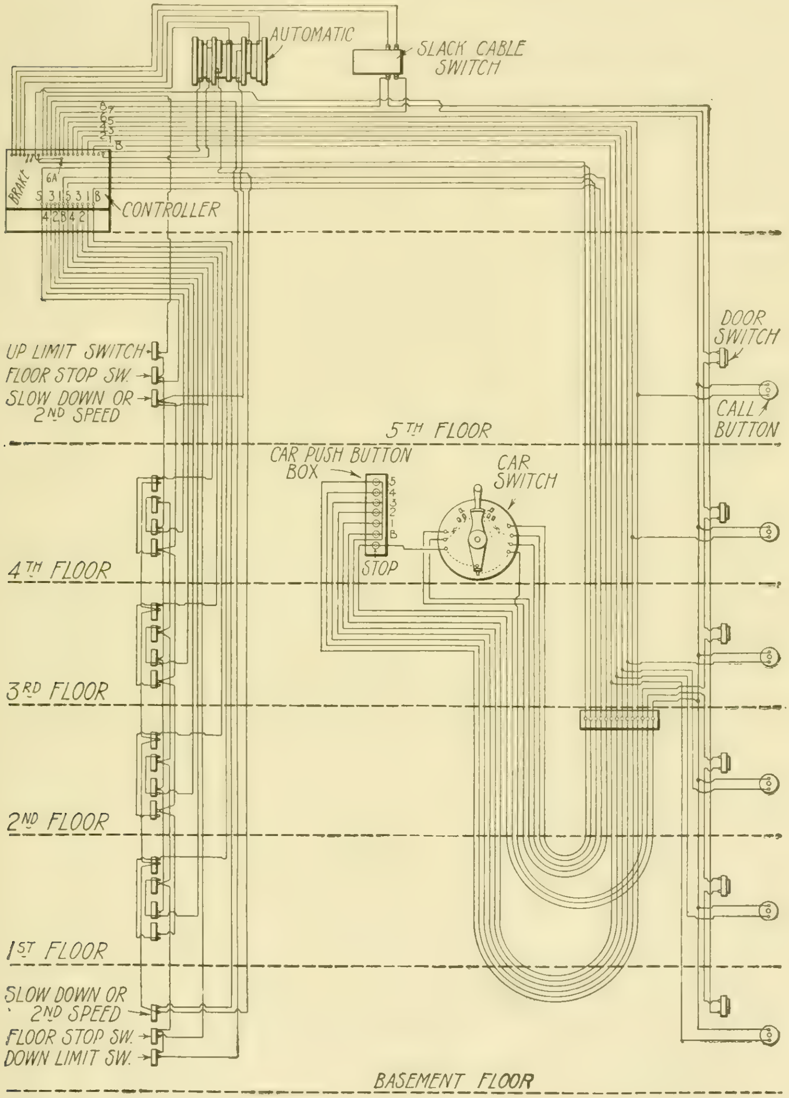


Fig. 143. Hatch Wiring Diagram of Six-Floor Combination Two-Speed Car Switch and Push-Button Control Elevator
Courtesy of Kaestner and Hecht Company

drum or to a cable sheave by sprocket wheels and a chain that when a brush is on the segment *I*, the car is at the landing corresponding to that brush. Hence in the case under consideration the car will stop at the fourth floor. It is seen that by this arrangement the brushes B, 1, 2, 3, and 4 are made to pass from one segment to the other as the car passes a floor, hence placing each of the brushes on the segments that will give the car the correct direction of motion for traveling to the floor desired by the passenger, when the correct push button is pressed.

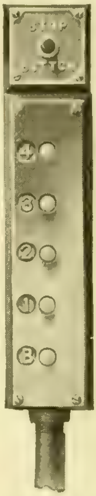


Fig. 144. Warner Cab Push Buttons

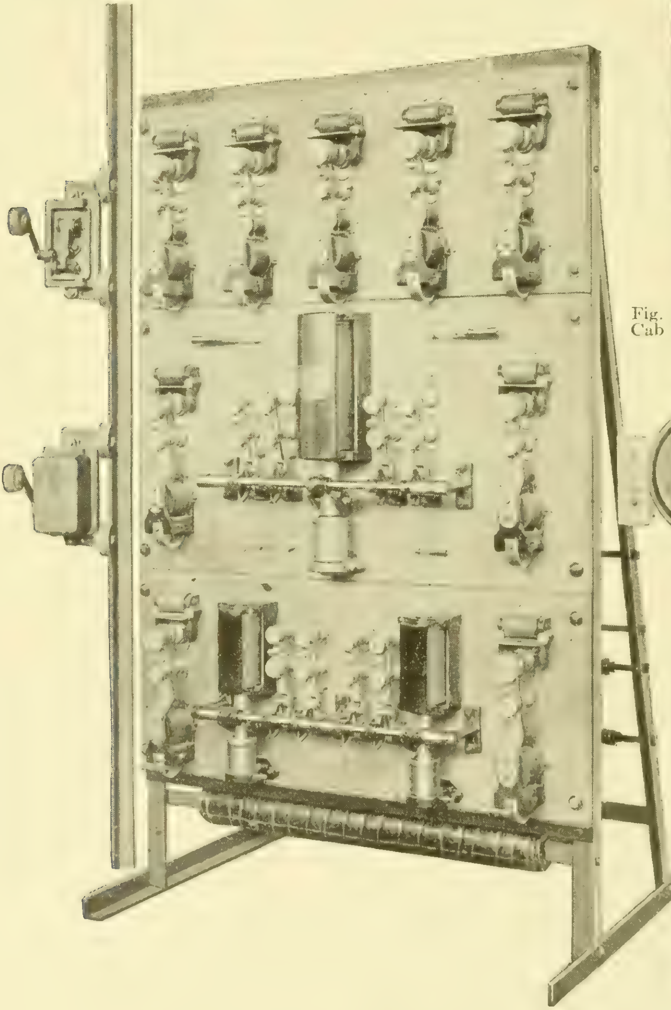


Fig. 145. Variable-Speed Full Magnet Elevator Controller
Courtesy of Kaestner and Hecht Company

The preceding description makes clear the method of push-button control when an alternating-current motor is used. In those cases where the direct current is used exclusively for operating the elevator, extensive modifications of the circuits must be made, as will be seen from the diagram shown in Fig. 142. However, the method of control is essentially the same as far as the manipulation in the car and at the various floors is concerned.

Referring to Fig. 140, it will be seen that there are five switches arranged at the top of the controller board; the two outer ones on either side are the line switches, while the center one is for closing the circuit to the brake. The four smaller switches and solenoid just below are as usual for controlling the acceleration of the motor. The five small spools at the bottom of the board are electromagnets for closing the line and brake switches and are operated by the push buttons and disk switches. As one of these small electromagnets is required for each floor, the machine shown in the illustration is a five-floor controller.

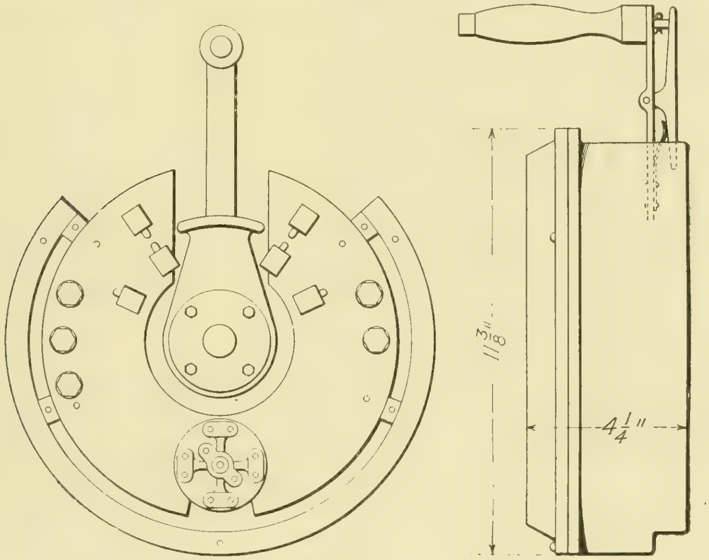


Fig. 146. Front and Side Elevations of Car Master Switch

The bank of push buttons in the cab comprises one button for each floor, appropriately numbered, and one button marked "STOP", Fig. 144, to be used in case the operator makes a mistake. If he selects the wrong floor, he simply pushes the "STOP" button and makes his selection anew.

Motor. The motor, Fig. 140, is an alternating-current three-phase motor. It might be mentioned here that any single-speed elevator may be operated on alternating current with magnetic control by using a small motor-generator set comprising an alternating-current motor and a direct-current generator to generate sufficient direct current to operate the electromagnets and solenoids for the control. (See the circuits for this arrangement at the lower left-hand corner of Fig. 141.) This small transformer set would run constantly and need not produce more than 10 to 20 amperes at 110 volts, the amount of current depending upon the capacity of the elevator. Most of the current would be used by the solenoid which releases the brake, the rest of the control never requiring more than 4 amperes.

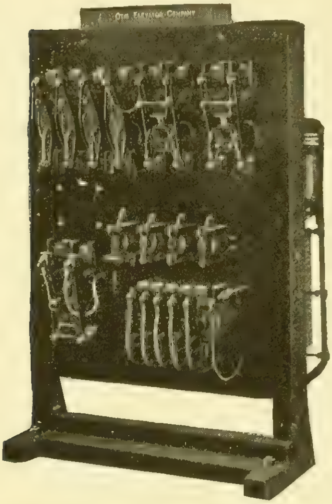


Fig. 147. Otis Direct-Current Elevator Controller

Variable-Speed Controller. The controller used for variable-speed elevators, running from 300 to 600 f.p.m., is shown in Fig. 145. Of the five switches located on the upper panel, the two outside ones on either side are the line switches, as before, while the center switch manipulates the field. In the center of the middle panel are the solenoid and the switches for cutting in and out the resistance in starting up on the first speed; the switch to the right in the same panel operates the dynamic brake; and that on the left operates an extra set of shunt fields used in connection with high-speed elevators for the purpose of giving still greater torque at starting, these shunt fields being auxiliary to the regular shunt fields of the motor. In the lower panel are located the switches and cut-outs of the two other speeds used in accelerating after starting.

To the right of this controller board is the operating switch which is mounted in the car. This is shown diagrammatically in Fig. 146. Moving the handle to the right produces motion of the car in one direction; and to the left, the reverse. It is so constructed that should the operator remove his hand from the lever, it will automatically assume the stop position shown in the cut. Just below this lever near the lower part of the case is a button, Fig. 145, which operates the emergency switch for opening the circuit in case of accident to the lever or its connections. At the left side of the case and attached to it is a small white panel carrying the reset for the circuit breakers which are used in connection with this type of elevator. These circuit breakers, in case the elevator should be overloaded or the voltage on the line become either abnormally high or low, will of themselves automatically open the circuit, thereby protecting the motor from the danger of burning out.

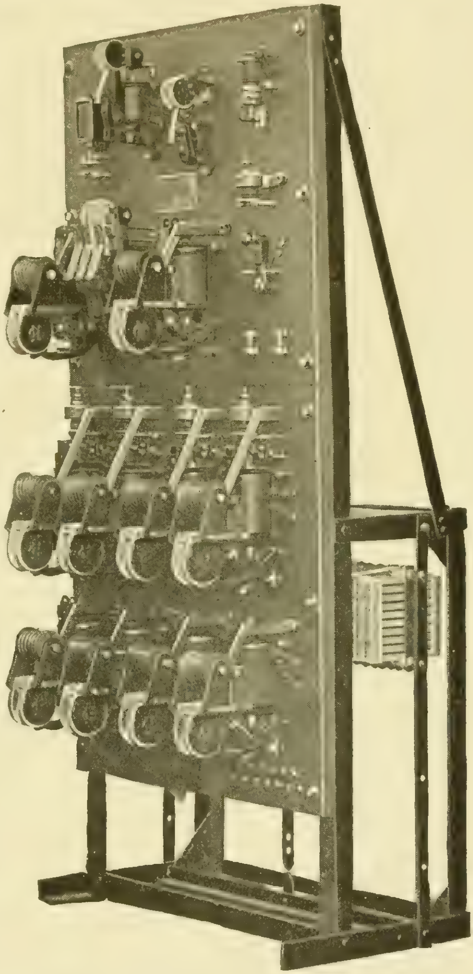


Fig. 148. Haughton Type of Controller
Courtesy of Haughton Elevator and Machine Company

At the extreme left of the illustration is a section of one of the steel guide rails in which the counterpoise weight travels. This has attached to it two hatch switches, already referred to as being used for the purpose of slowing down and stopping the car at each end of its run. A cam attached to the car presses back the lever shown at the side of the switch, thus producing the desired results. The upper switch is shown with the cover removed. These switches are clamped to the guide rail in such a way that they may be readily

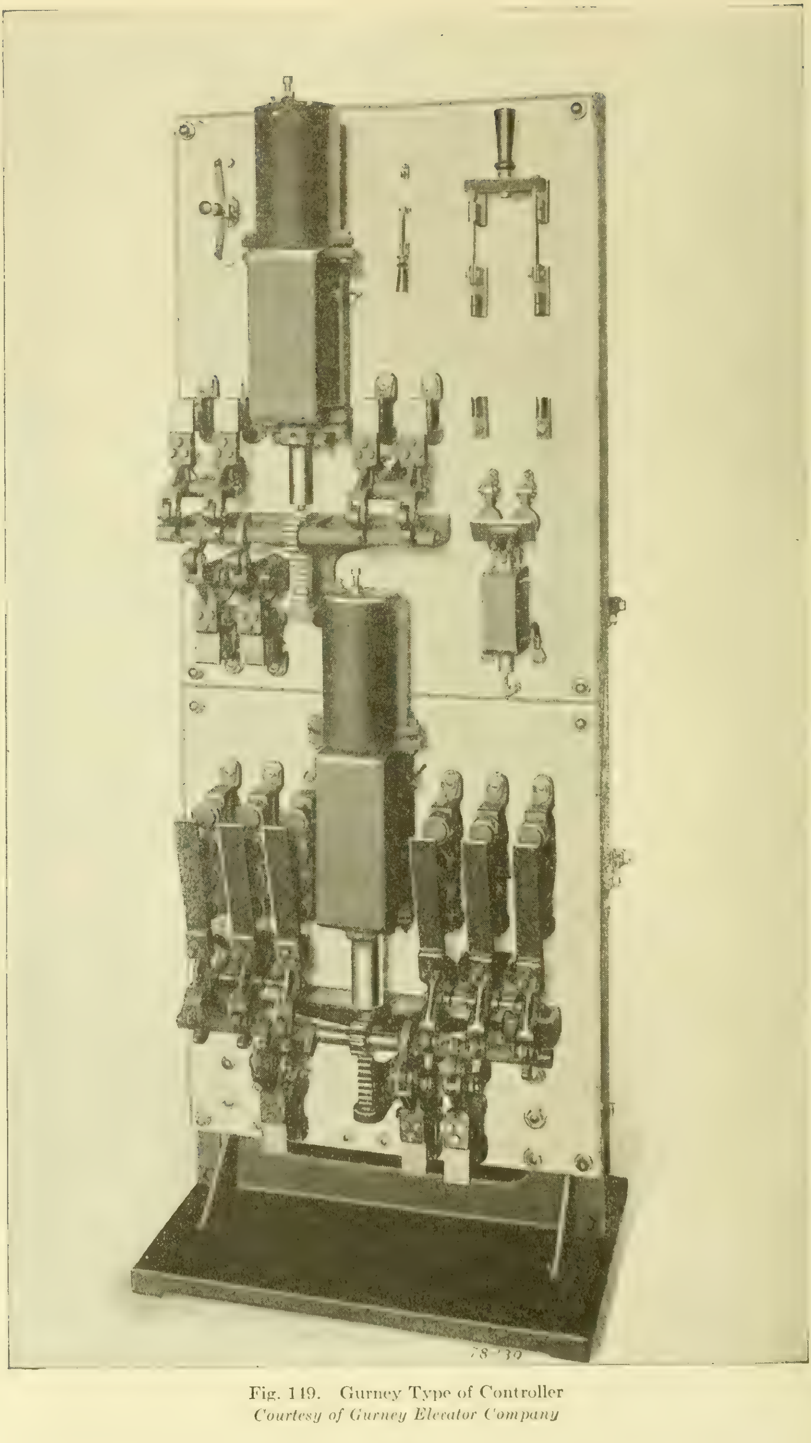


Fig. 149. Gurney Type of Controller
Courtesy of Gurney Elevator Company

adjusted for position with respect to the upper and lower landings, and in actual use are set several feet apart, instead of close together, as shown in the illustration.

A close observation of the panels of the two- and three-speed controller (Figs. 136 and 138) will show one or more single-pole knife switches. These are used for the purpose of throwing out of service the extra speeds, thereby converting the machine into a single-speed elevator for the time being; by this means an elevator designed to lift a moderate load at a high speed may be used for lifting a heavy load at about half speed. This arrangement, while useful for an occasional load, is not intended nor is it suitable for continuous service, being liable under such conditions to overheat the motor windings.

For the foregoing illustrations we have selected representative types of one of the best manufacturers. To illustrate differences in design, controllers of other standard makes are shown in Figs. 147 148, and 149.

TRANSMISSION

The motor and controller having been discussed, only the transmission needs to be considered in order to complete what is usually known by elevator builders as the *electric engine.*

Location of Engine. The different forms of transmission vary somewhat with the location of the engine. This is, in some cases, placed on a foundation in the lower story, Fig. 150, or alongside the hatchway on any other floor of the building, but the most usual location is directly over the hatchway or shaft, Fig. 151. A penthouse is made especially for it above the roof, the engine resting on a floor supported by steel I-beams which, in turn, are carried by the walls of the building and the hatchway. The engine is securely bolted to these beams and slots are cut through the floor for the passage of the cables which connect the winding drum with the car and counterweights. The latter arrangement has the advantage of a more direct connection between the engine and the car and the elimination of the overhead sheaves which are necessary when the engine is located below and adjacent to the hatchway. The placing of the engine overhead does not always do away with the necessity for overhead sheaves for, where the hatchway is large or the necessary location of the engine is such that the diameter of the winding will

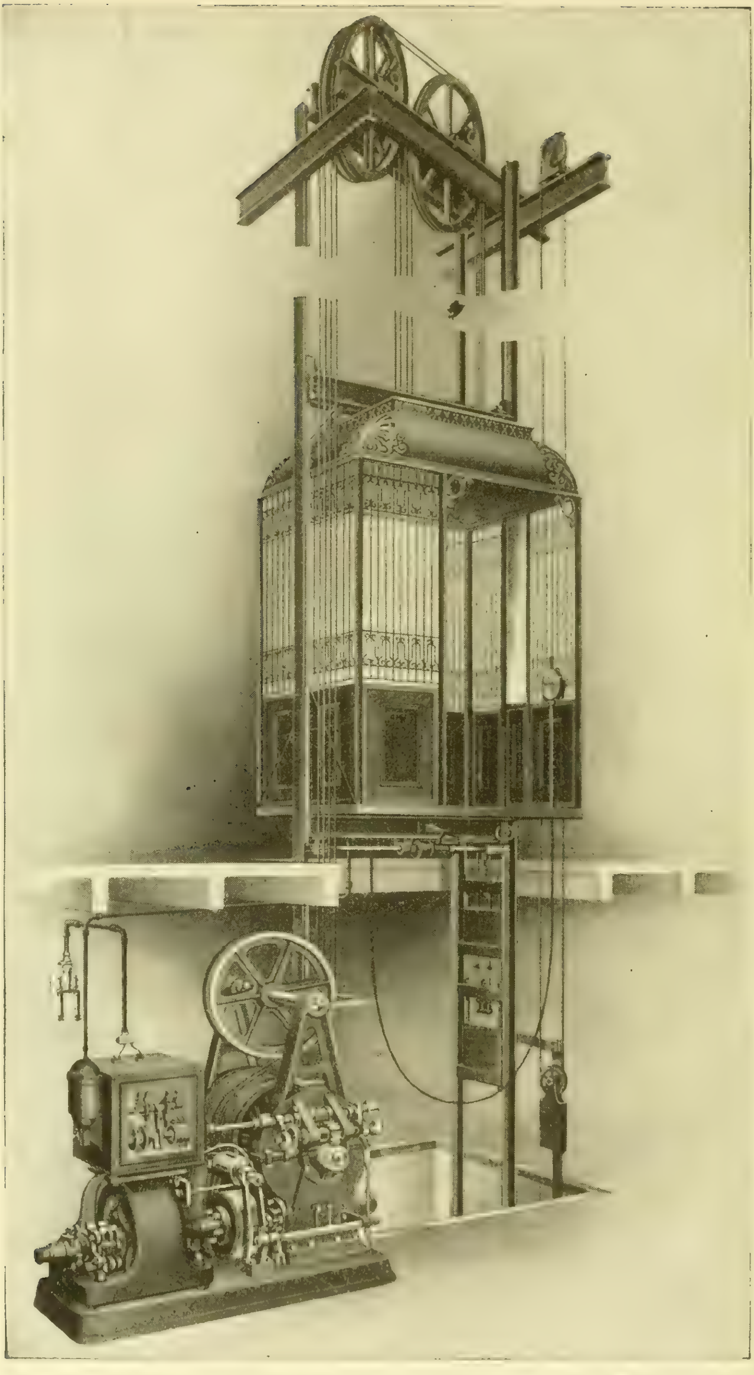


Fig. 150. Basement Type of High-Speed Passenger Elevator with Full Electric Control
Courtesy of Warner Elevator Manufacturing Company

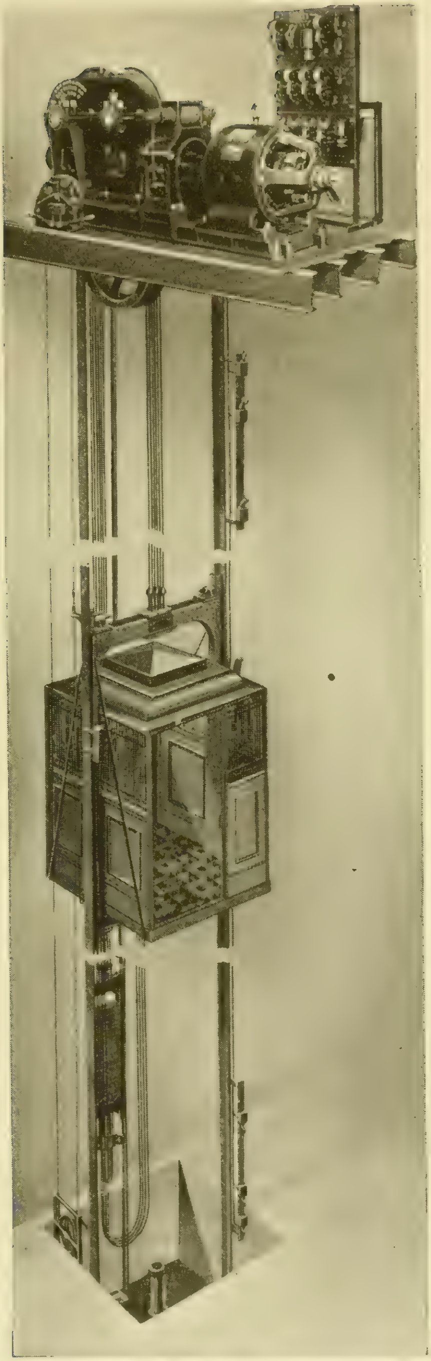


Fig. 151. Overhead Type of Passenger Elevator for Heavy Duty with Full Magnet Control
Courtesy of Haughton Elevator and Machine Co.

not span the distance from the center of hatch to center of weight slides, auxiliary sheaves become a necessity.

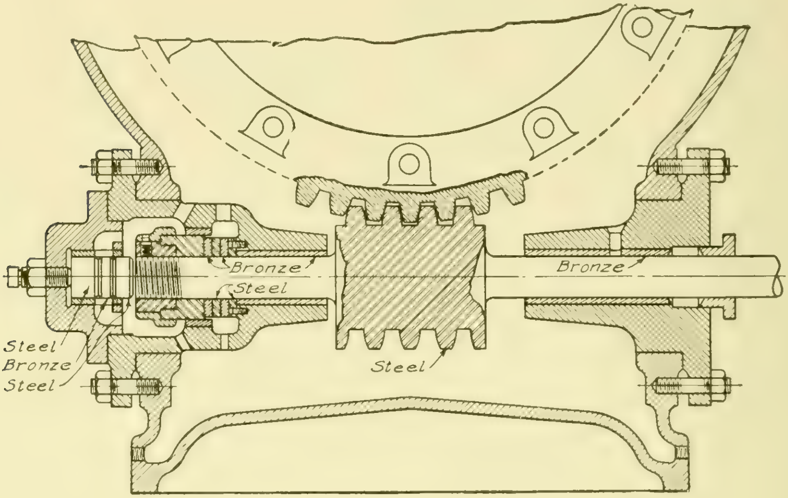


Fig. 152. Single Gear Worm and Wheel

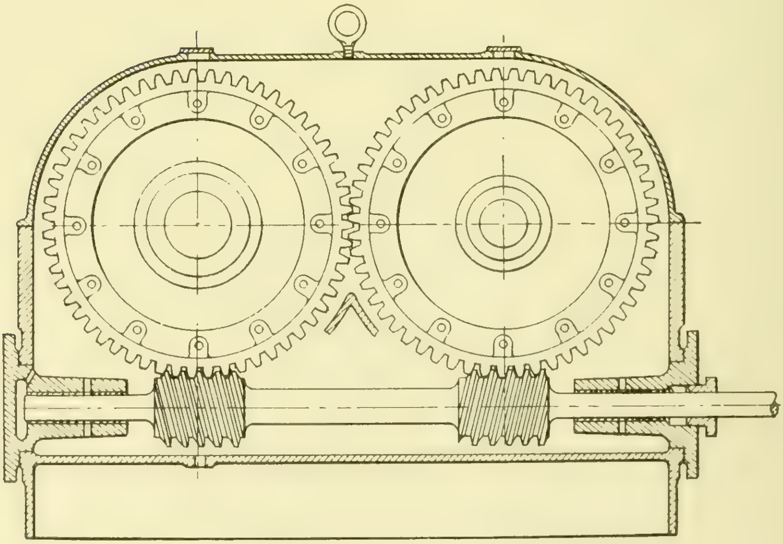


Fig. 153. Tandem Gear Which Avoids End Thrust

It cannot be doubted though that when the engine is placed overhead, a great deal of friction is dispensed with, and some room

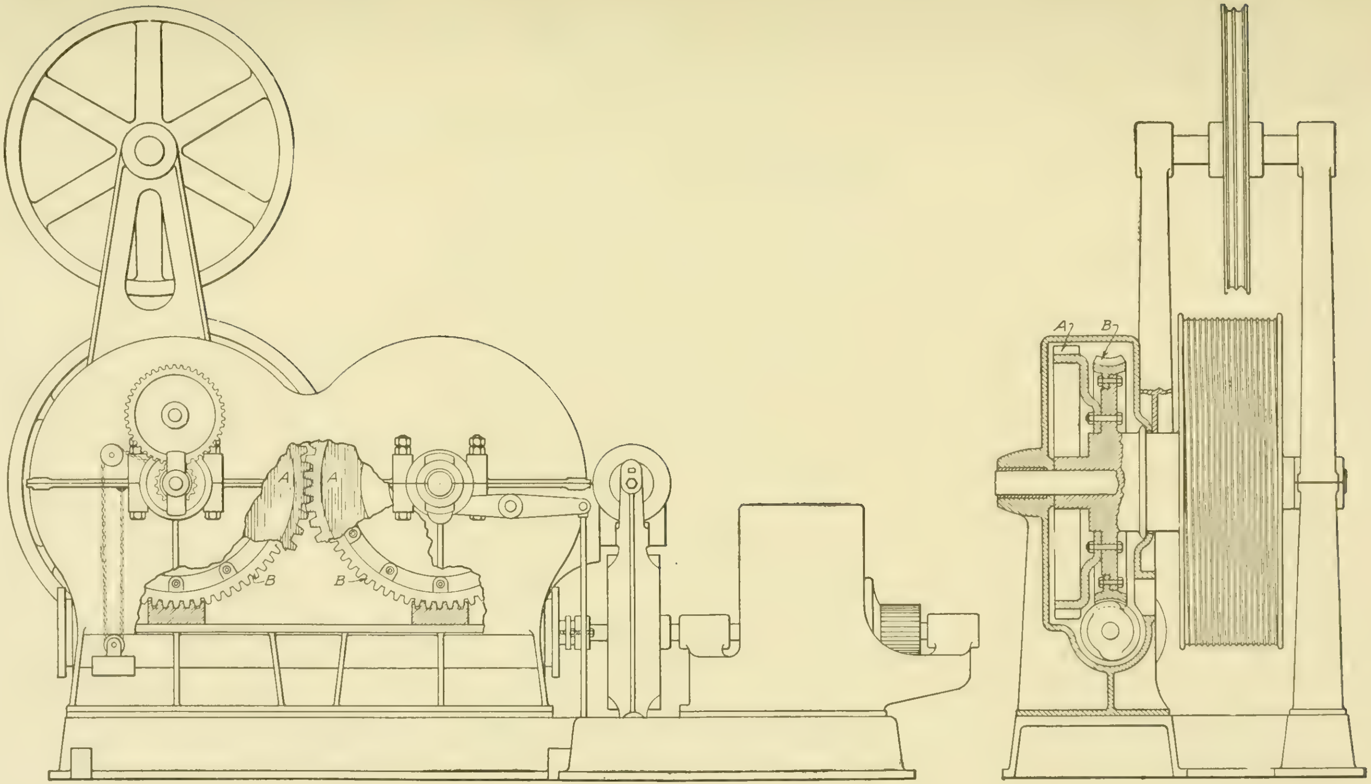


Fig. 154. Early Design of Spur Gears and Tandem Worm
Courtesy of Kaestner and Hecht Company

in the building saved for other uses. This arrangement calls for either brick walls surrounding the hatchway or girders at the roof sufficiently strong to carry the weight of the engine, car, counterpoise weights, and loads to be lifted, as well as the weight of the wall and roof of the pent house. The support must also be strong enough to resist the impact caused by the stopping and starting of the elevator.

Worm and Wheel. *Single Gear.* The power of the motor is transmitted to the winding drum and thence to the car or platform by means of a mechanism called a worm and wheel, Fig. 152 The shaft on which the worm is cut is direct-connected to the armature shaft of the motor by means of an insulated coupling (see Fig. 126), one-half of which is shaped like a pulley of very heavy design and liberal width of face. This coupling serves as a brake pulley for use in stopping the machine and for holding it while being loaded and unloaded.

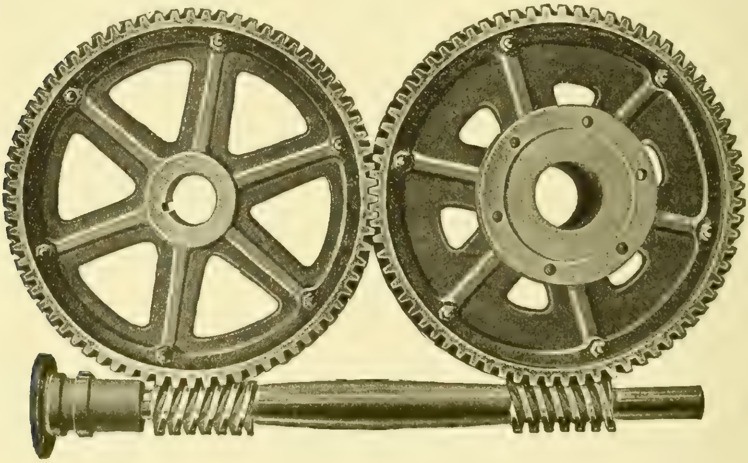
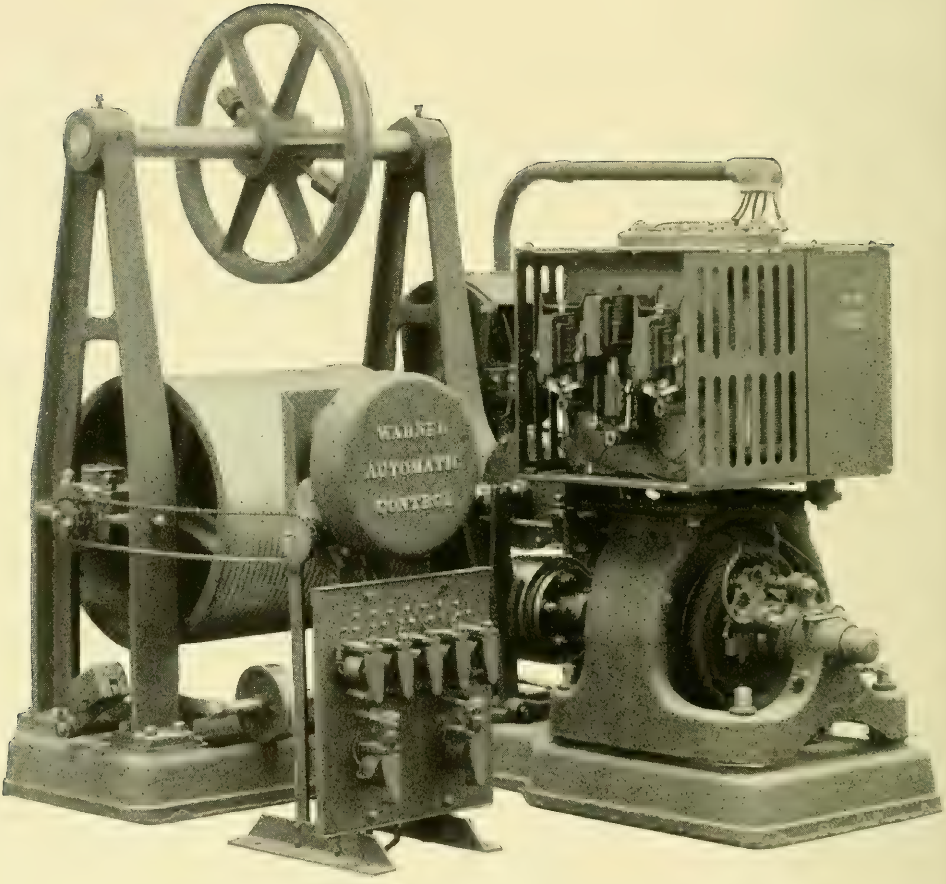


Fig. 155. Gurney Tandem Worm Gear Drive

Tandem Gear. Another type of worm gear—called the tandem gear—is quite an old idea, having been patented over thirty years ago by a Boston firm. It consists of two worms or coarse pitch screws, Fig. 153, usually forged solid on one shaft; one screw being cut with a right-hand thread and the other with a left-hand thread. As originally designed by the inventors, the worm gears used were made with straight faces—the teeth being cut at the angle of the



SMALL ALTERNATING-CURRENT AUTOMATIC PUSH-BUTTON ELEVATOR ENGINE
Courtesy of Warner Elevator Manufacturing Company

thread of the worm—and the gears were set so that they meshed together. Later some makers used spur gears in addition to two worm wheels, Fig. 154, and bolted them together in pairs. The wheels were made with concave faces and teeth, as shown in the end elevation at the right, and the spur gears were enough larger in diameter than the worm gears to prevent the latter from touching each other when the spurs were in mesh.

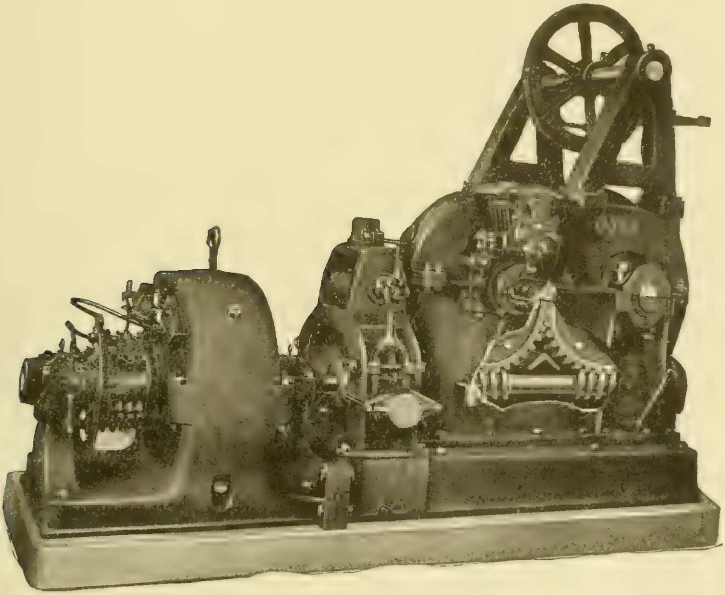


Fig. 156. Double-Screw Direct-Current Elevator Machine with Switch Control
Courtesy of Otis Elevator Company

Another and better way to secure these advantages is to use two spiral gears meshing together with the worms driving them, as shown in Fig. 155. Fig. 156 gives the general appearance of a tandem-geared engine.

The advantages claimed for the tandem-geared engine are double power and durability. The load, being divided between two worms and gears, produces only one-half the strain on the teeth of each, but it is a more expensive machine to build and occupies more space. However, for heavy loads the arrangement is certainly preferable to a single-geared machine having an enormous gear and drum. Another advantage is that the gears used in the tandem machine are about the same size as those in general use, and therefore no special patterns or tools are required for the production of a machine of double capacity except the gear case and the bed, or base plate, of the engine. This tandem construction also eliminates the end thrust, which is discussed on page 204.

Provisions for Speed and Load Variations. *Change of Gear Pitch.* In all these machines it is customary to so design the gear cases that a choice of any of two or three pitches of gear and worm may be used, the range for the smaller sizes being from $\frac{7}{8}$-inch to $1\frac{1}{2}$-inch pitch, Fig. 157, with lifting capacity of 1500 to 3000 pounds, and from $1\frac{1}{4}$-inch to $1\frac{3}{4}$-inch for the heavier capacities. As the worm gear only moves the space of one tooth for each revolution of the worm shaft, the latter must revolve as many times as there are teeth in the gear for each revolution of the drum; so if the drum, in order to make the car travel at the required speed, had to make 15 r. p. m. and the worm gear had 50 teeth, the speed of the worm shaft and consequently that of the motor would have to be 750 r. p. m. A different speed of the drum may be brought about by a choice of any one of two or three pitches of worm gear. Of course, the same result could be accomplished by modifying the diameter of the drum, but this has some limitations in that the drum must not be so small in diameter as to have a bad effect on the cables, nor so large that the pressure between the teeth of the gear and threads of worm will cause excessive wear.

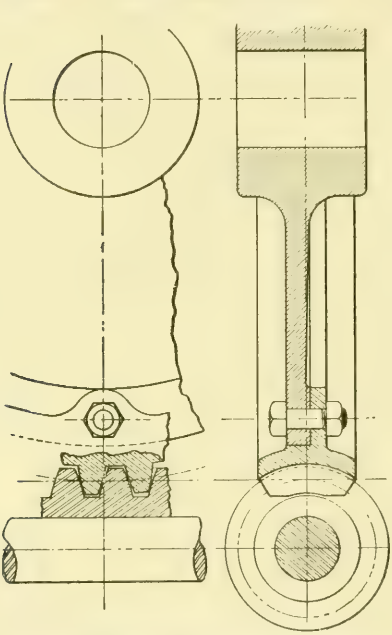


Fig. 157. Diagram Showing Arrangement for Changing Gear Pitches

Double-Threaded Worm. Where greater speed of car is desired, a double-threaded worm may be used, thus giving double speed to the drum. Therefore, in a machine built so as to allow a choice of any one of three gears and worms, and, in addition, the double pitches just spoken of, there are six available speeds. These are capable of further variation either by the use of high-speed or low-speed motors or by varying the diameter of the hoisting drum, thus providing a possible variation of car speed of from 100 to 200 f. p. m.

Reduction Gear. When a car speed of from 50 to 60 feet is desired, it is customary to reduce the number of revolutions of the drum by means of a reduction gear, Fig. 158. The gear used in this machine is a spur of the "internal" type and, as the pinion usually has a ratio of about 4 to 1, a high speed motor may be used. Of course when the reduction gear is used, the pinion is placed on the same shaft as the worm gear and the drum runs in separate bearings. The principal reason for the use of an internal spur gear is that it does not change the direction of the drum's rotation, while a spur gear of the ordinary type would. It is always best that the drum in lifting the load should revolve so as to bring the thrust of the end of the worm shaft towards the back end of the gear case.

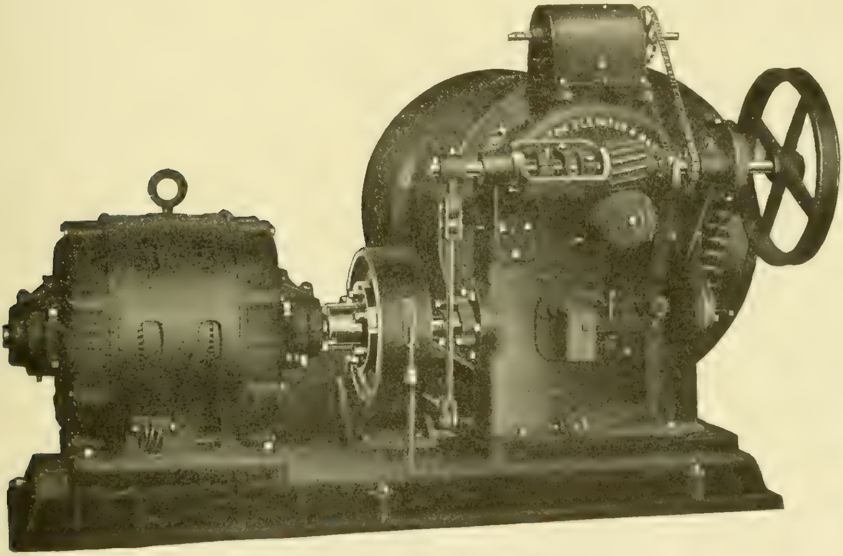


Fig. 158. Internal Gear Type of Drive
Courtesy of Haughton Elevator and Machine Company

End Thrust of Worm Shaft. In order that the reader may have a clear idea of the action of the end thrust of the worm shaft in a direct-connected single-gear machine, the details of the back bearing are given in Fig. 159. An examination of Fig. 152 shows that this end thrust is a very important thing, as upon the resistance of the back bearing depends the lifting power of the machine. The bearing shown is the most common form of thrust bearing and is so arranged that the end thrust is capable of adjustment in both directions. For the back thrust, a steel toe or thrust plug with a taper shank fits into a hole bored in the end of the worm shaft at *B*, Fig. 159. This is held in place by another steel plug *C*, with a hard bronze disk *D* between them. This steel plug *C* is adjustable for wear by means of a set screw, and is kept from revolving by a pin, not shown. The bronze disk, however, is free to revolve with *B* and bears the brunt of the wear.

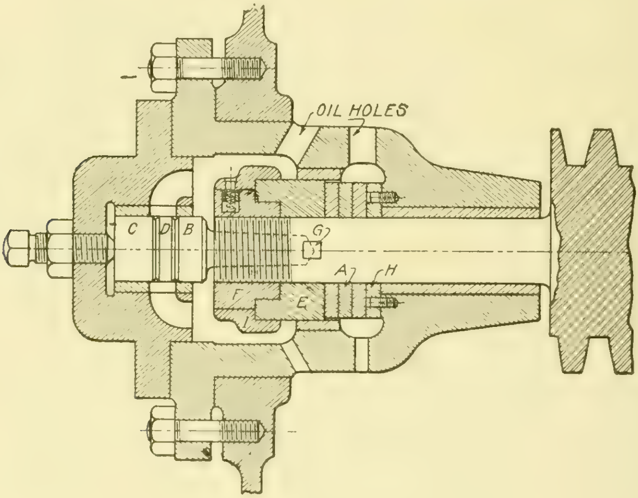


Fig. 159. Section of Worm Shaft Thrust Block

The forward thrust due to the action of the counterpoise weights is taken on the alternate steel and bronze rings *A*, which are also free to revolve; the steel collar *E* is kept from revolving by the pin *G*, but has a longitudinal slot in it which fits over *G* and allows some end motion. The nut *F* is screwed on the end of the worm shaft and, by tightening up this nut when necessary, any lost motion in the forward thrust may be eliminated. The nut is kept in place by the keeper *I*. That part of the gear casing which contains this thrust compensator also serves as the back bearing for the worm shaft. It is bushed or lined with bronze, and oil holes are provided for free access of oil from the reservoir which lubricates the worm and gear.

This device is but one example of the many contrivances of this nature and is sufficient to illustrate the method of taking care of the end thrust. Some makers use steel balls between the thrust plates with a view to reducing friction to a minimum. Fig. 160. There are some objections to the use of balls as they are liable to crush under heavy loads, the lost motion cannot be so easily taken up, and they wear grooves in the plates or rings. Some makers consider that the oil from the reservoir which lubricates the worm and gear is liable to contain grit and cuttings from the gear and, therefore, prefer to lubricate the thrust bearing by means of a special oil cup in the outside of the gear casing.

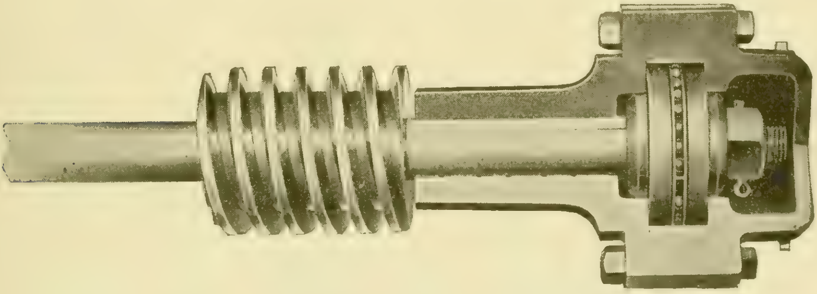


Fig. 160. Ball Bearing Thrust Block for Worm Shaft
Courtesy of Warner Elevator and Manufacturing Company

Winding Drum and Cables. Elevators which have a travel of less than one hundred feet seldom are made to run at a speed of more than two hundred and fifty f. p. m., and more frequently less than that. In the case of what is called the "drum" type of machine, the lifting and drum counterweight cables are attached to the drum, which is grooved spirally with a concave groove to receive and guide the cables. Each cable, or to be more accurate each pair of cables, has a separate groove, for there are but two grooves on the drum, and the cables are so attached and arranged that, while the lifting cables are being wound up, the counterpoise cables which are also attached to the drum, are being unwound. A careful inspection of Fig. 150 will enable one to follow the two sets of cables to the car and counterpoise weights. The "idler" pulley slides from side to side as the cables wind on or off. It is seen, therefore, that in pairs they alternately use the same grooves. These grooves, or scores as they are called, are, in the case of the overhead type, so made that they run from the ends of the drum towards the center, one groove on each side; when the engine is set to one side of the hatchway, either on a foundation or on suitable framing on one of the other floors of the building, the grooves run in pairs side by side from one end of the drum to the other and are made to lead right hand or left as the conditions require.

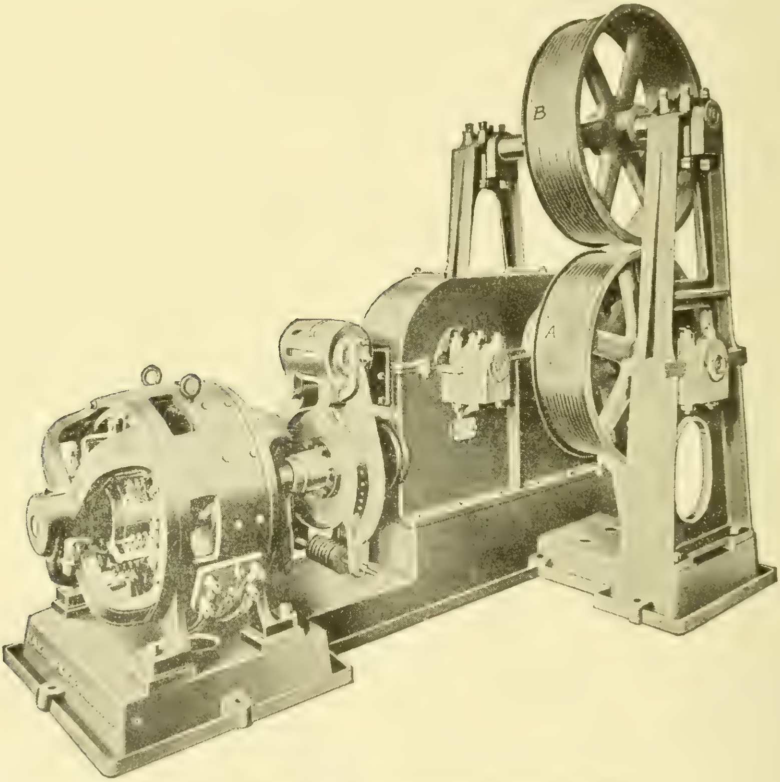


Fig. 161. Heavy Duty Tandem-Gear Traction Machine

Counterpoise Weights. Two counterpoise weights are used: one which is attached to the drum to offset a certain percentage of the load to be lifted; and another used to counterbalance the car. The latter weight travels in the same runways as the drum counterweight, but above it, grooves or channels being cast in this upper weight to allow the supporting cables for the lower weight to pass through. The cables from this upper, or car, counterpoise pass up the hatchway and over sheaves or grooved wheels set at the top of the hatchway and thence down to the car itself, Fig. 150. It will be seen from the above description that in all six cables are used, and as the principal cables are rigidly attached at one end to the winding drum, the relation of the car to the number of revolutions of the drum is always fixed. It is evident, then, that a mechanical automatic limit stop, driven from the drum shaft itself, will always be sure to stop the engine at the end of the car travel.

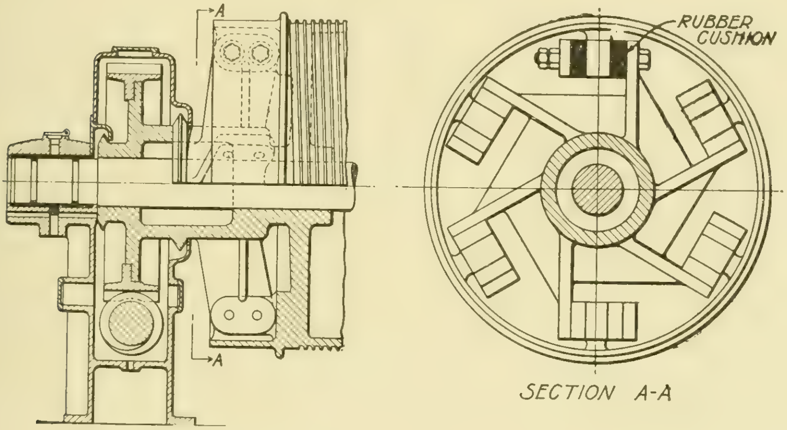


Fig. 162. Diagram Showing Six-Armed Yoke for Driving Traction Elevator

TRACTION ELEVATORS

The transmission previously described is designed for vertical lifts of one hundred feet or less. When the car travel is from one hundred twenty-five to two hundred fifty feet, new conditions prevail. *First*, the speed must be greater or the elevator will require too great a time to make a round trip and will, in consequence, prove inadequate for the service required; *second*, the drum face required to wind up so much cable will be too wide to be practical in an ordinary width of hatchway; and *third*, the weight of such extreme

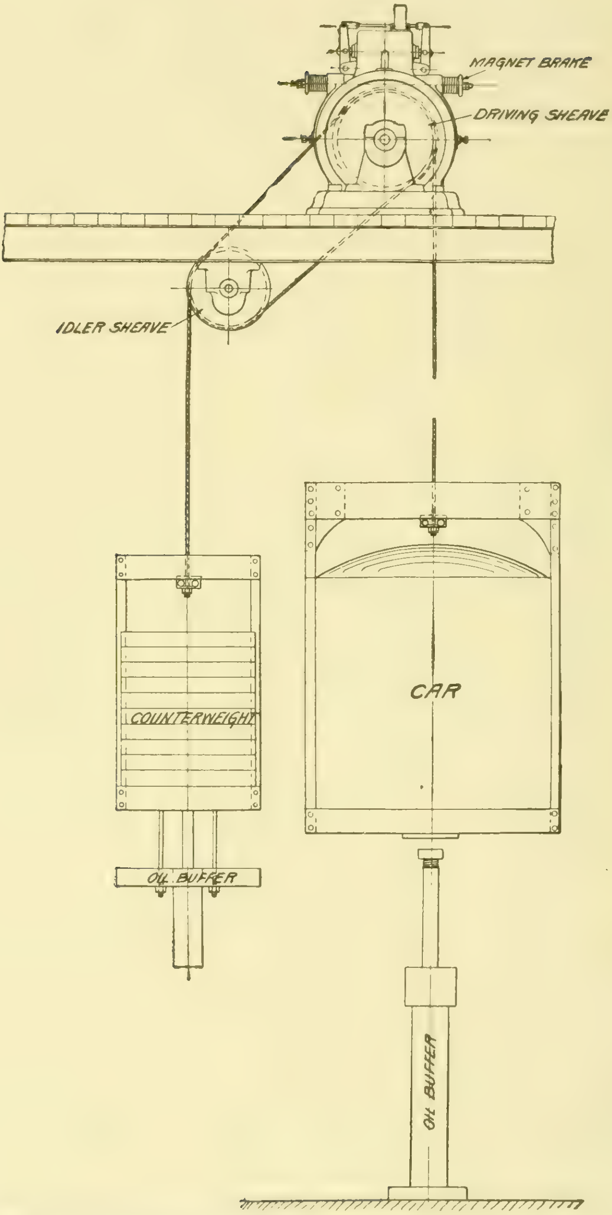


Fig. 163. Diagram Showing General Arrangement of Roping for Traction Elevator
Courtesy of Otis Elevator Company

lengths of cable will cause a series of vibration in the lifting capacity of the machine. To overcome these difficulties, another type of machine, called the traction elevator, has been devised.

Drum and Cable Arrangement. In engines of this type the wide faced drum is not used, being replaced by a drum not more than 12 inches wide, *A*, Fig. 161, with twelve grooves which are no longer spiral but are separate and distinct grooves such as are turned in a sheave; in fact, the drum is simply a sheave having more than the usual number of grooves. This drum is attached to or driven by the gear through a spider or six-armed yoke, Fig. 162, which engages with the arms of the drum. Rubber cushions are inserted at the points of contact to help soften any jar occurring at stopping and starting, and are held in position by suitable bolts and plates. Directly below or above this drum—according to whether it is an overhead engine or one arranged to be below on a foundation—is placed the "idler" sheave or drum *B*, Fig. 161, with the same number of straight grooves turned on its periphery, and running independently of the machine on a shaft and bearing of its own.

The cables are six in number and are passed over one of these drums and under the other in succession, Fig. 163. It is, however, always so arranged that they go twice partially around the engine drum and only once on the idler, although frequently, before leading into the hatchway, they are deflected by the idler in order to lead them plumb over the weight or over the car or into the hatchway, as the case may be. This accounts for the necessity of having the same number of grooves in each drum. One end of each of these cables is attached to the car and the other end to the counterpoise weight. It will be seen, therefore, that the cables are not attached to the drum at all, but depend on the friction with the face of the driving drum to transmit the power from the drum. Hence, the name *traction* machine. Figs. 161, 164, and 165, give a good idea of the machines of this type.

Limit-Stop Arrangements. *Hatch Switches.* With the arrangement of drum and cable just mentioned, the same width of face of drum will do for any height of car travel, but as the cables are not attached directly to the drum, the use of a mechanical limit stop is inexpedient, owing to a slight amount of slippage due to the stretching of the cables, quick starts and stops, and other causes. On this account a limit stop which was actuated by the engine would not remain accurate for long. This uncertainty has been removed by the use of hatch switches, as shown at the left of Fig. 145. These switches are attached within the upper and lower limits of travel,

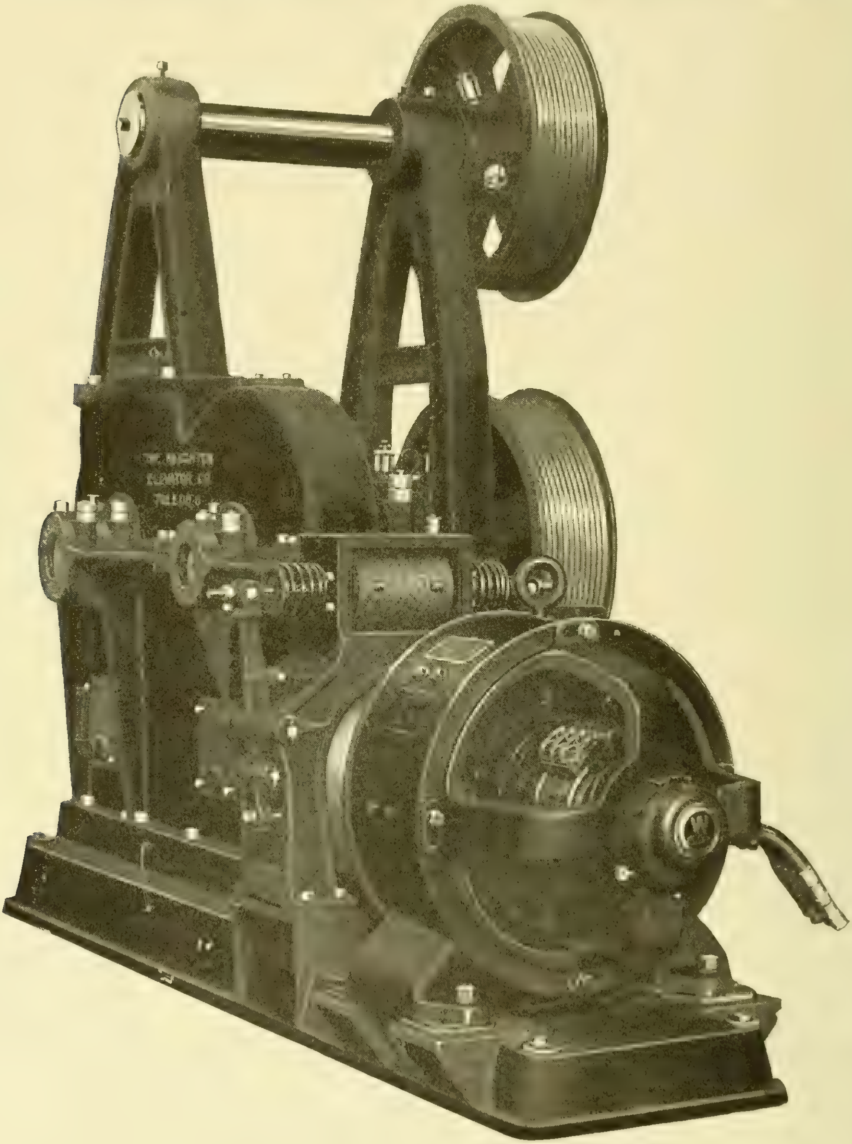


Fig. 164. Haughton Type of Tandem-Gear Traction Elevator
Courtesy of Haughton Elevator and Machine Company

usually to one of the guides, so that the car in passing pushes back a lever and thereby opens or closes a circuit as required. For high speed three of these switches are used at each limit of travel: the first to slow down, the second to stop, and the third as an emergency switch, setting fairly close to the stop switch, which closes a circuit to a solenoid, thus applying an extra squeeze to the brake.

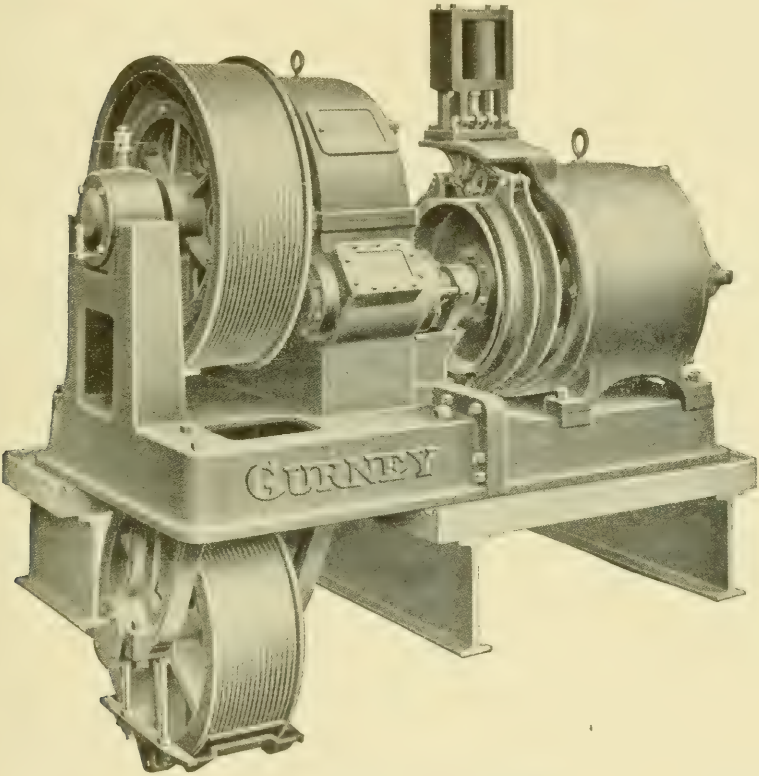


Fig. 165. Gurney Type of Traction Elevator
Courtesy of Gurney Elevator Company

Oil Buffers. In addition to the above safeguards, oil buffers are used below the car and the counterpoise weight, one type being shown in Fig. 166. The device consists of a plunger hanging vertically downward from the car and operating in a hollow cylinder filled with oil. A tank or reservoir of somewhat greater capacity than the cylinder takes care of the excess of oil when the plunger operates. If the car slips by the landing, the lower end of the cylinder strikes a stop such as a pier or beam located at this point for the purpose, and the car or counterweight forces the plunger into the cylinder. The oil escapes into the tank through grooves cut in the surface of the cylinder, but as its passage through these grooves is necessarily slow, the car is slowly brought to rest.

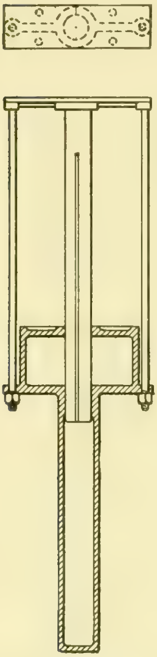


Fig. 166. Oil Buffer Attached to Car

In case the car is at the top landing when a slippage of this kind occurs, the counterpoise weight —which is at the bottom of its travel—performs the office by slackening the cables on the drum as soon as its descent is retarded by the oil buffer, thus destroying the tractive power of the drum for the time being.

Another type of oil buffer which is set in the bottom of the hatchway is shown in Fig. 167.

“One-to-One” Traction Type. The form of drum just described, with its accompanying idler and other accessories, may be used with any high-speed electric engine, whether it be a single worm and gear or a tandem machine. The latter are more frequently used, however, because the wear is divided between two worms and gears and the mechanism is less liable to heat or get out of order. These geared machines, however, are suitable only for moderately high speeds up to 400 f. p. m.; when a higher speed is desired, another form—known among elevator makers as the “one-to-one” engine—has been adopted. It derives its name from the fact that the drum performs one revolution to every revolution of the motor, the

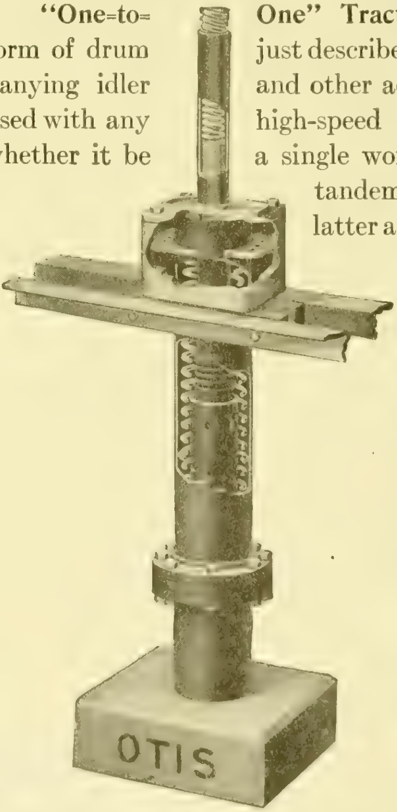


Fig. 167. Otis Oil Buffer with Spring Return

drum being keyed directly on the armature shaft, which is extended for the purpose, and an additional or outside bearing provided for its support.

A machine of this type is shown in Fig. 168. A motor of special design is used, which is provided with windings for acceleration and retardation, and whose armature is wound for very slow speeds, viz, 50 r. p. m., and in many cases 35 r. p. m., for the full or normal speed. A motor running at either of these speeds and a drum of, say, 34-inch diameter will produce a car speed of from 300 to 450 f. p. m., and with a little higher motor speed, say 60 to 70 r. p. m., a car speed of from 500 to 600 f. p. m. may be obtained.

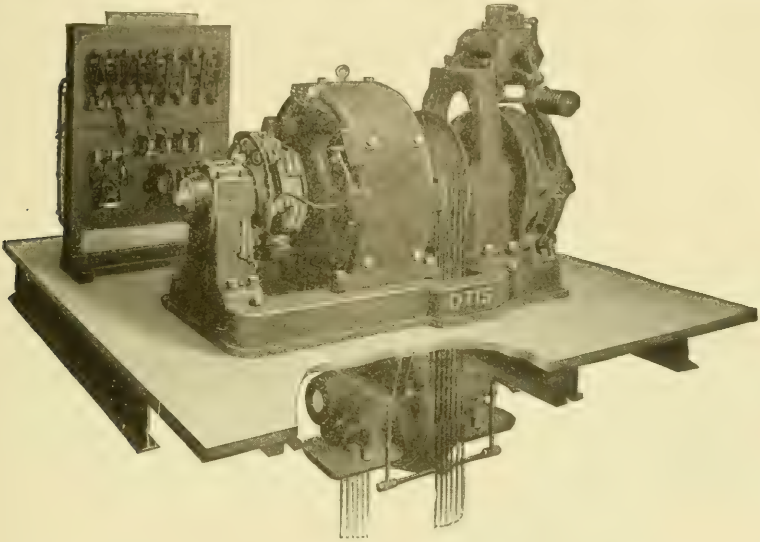


Fig. 168. Gearless Traction Elevator with "One-to-One" Roping
Courtesy of Otis Elevator Company

When engines of this type are used, the armature shaft must be of ample diameter—5 inches to 6 inches according to the duty required of it—and the drum must be cast with a broad and heavy brake pulley integral with it. This pulley is of the same diameter as the drum, has a full 12-inch face, and has fitted to it a very powerful brake, applied in the usual manner by strong spiral springs and a very powerful solenoid for the release. The method of control of this elevator is similar to that used with the geared machine except that the motor is fitted with a speed governor driven from the armature shaft, which is designed, in case of undue speed, to close a circuit to the solenoid, and at the same time to open the main circuit and thereby stop the engine.

"Herringbone" Spur-Gear Type. The latest type of electric elevator is what is called the "herringbone" spur-gear machine, Fig. 169. It consists of the usual bed plate with gear case, drum, bearings, and motor, mounted upon it, but instead of the worm and gear, a bronze spur gear and pinion are used to drive the drum. The ratio between gears is about 5 to 7 and the teeth in gear and pinion converge from the center of its face outward at an angle of about 60 degrees, Fig. 170; hence the name herringbone.

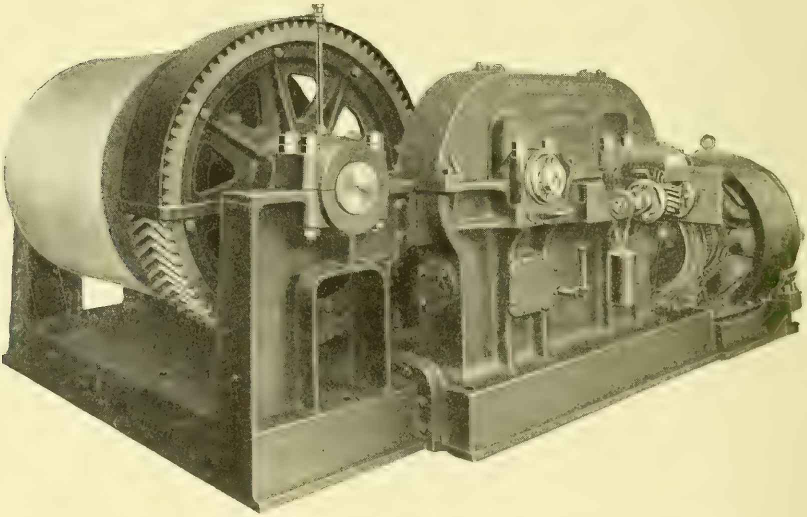


Fig. 169. Tandem-Gear Elevator with Herringbone Reduction Gearing
Courtesy of Gurney Elevator Company

There is nothing new about this type of spur gear, as it has been in use for mill purposes for at least a century. It was originally designed to impart a smoother motion to the driven machines and also to give greater strength to the teeth, but until recently the only method of producing it was by casting and, of course, cast gears were not applicable to elevator service. However, cut gears of this description have now been successfully produced and they are being adopted in many other lines.

The advantages of the herringbone gear are a minimum of friction as compared with the worm and worm gear; smoother running than with the teeth cut straight across the face; and greater strength due to the diagonal position of the teeth, which allows a greater number of teeth to be in mesh with the pinion at one time.

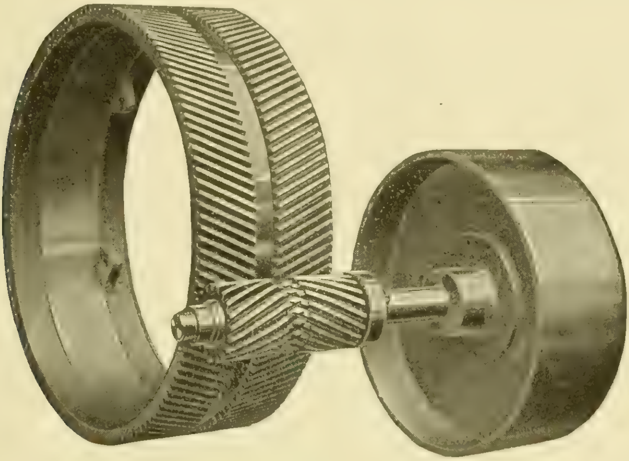


Fig. 170. Helical Gear Rim, Pinion, and Brake Pulley
Courtesy of Gurney Elevator Company

The disadvantage, which is common to all spur gears, is its extreme liability to race when lowering a heavy load or when an empty car is ascending. To guard against this, the engine must be provided with a centrifugal governor, Fig. 171, on the pinion shaft, which applies a brake momentarily when a certain speed is exceeded.

In this machine the motor is coupled to the pinion shaft to which the braking device is attached. The hoisting drum is provided with a heavy wide brake pulley such as is used on the

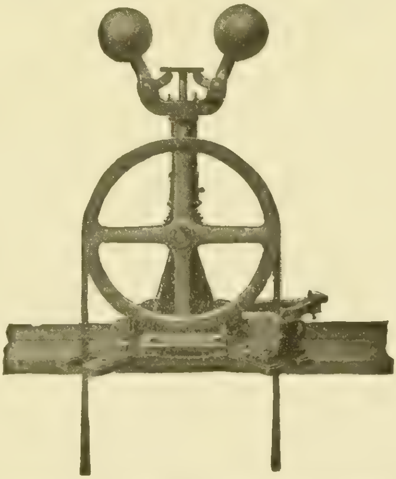


Fig. 171. Gurney Centrifugal Safety Governor Thrown into Operation

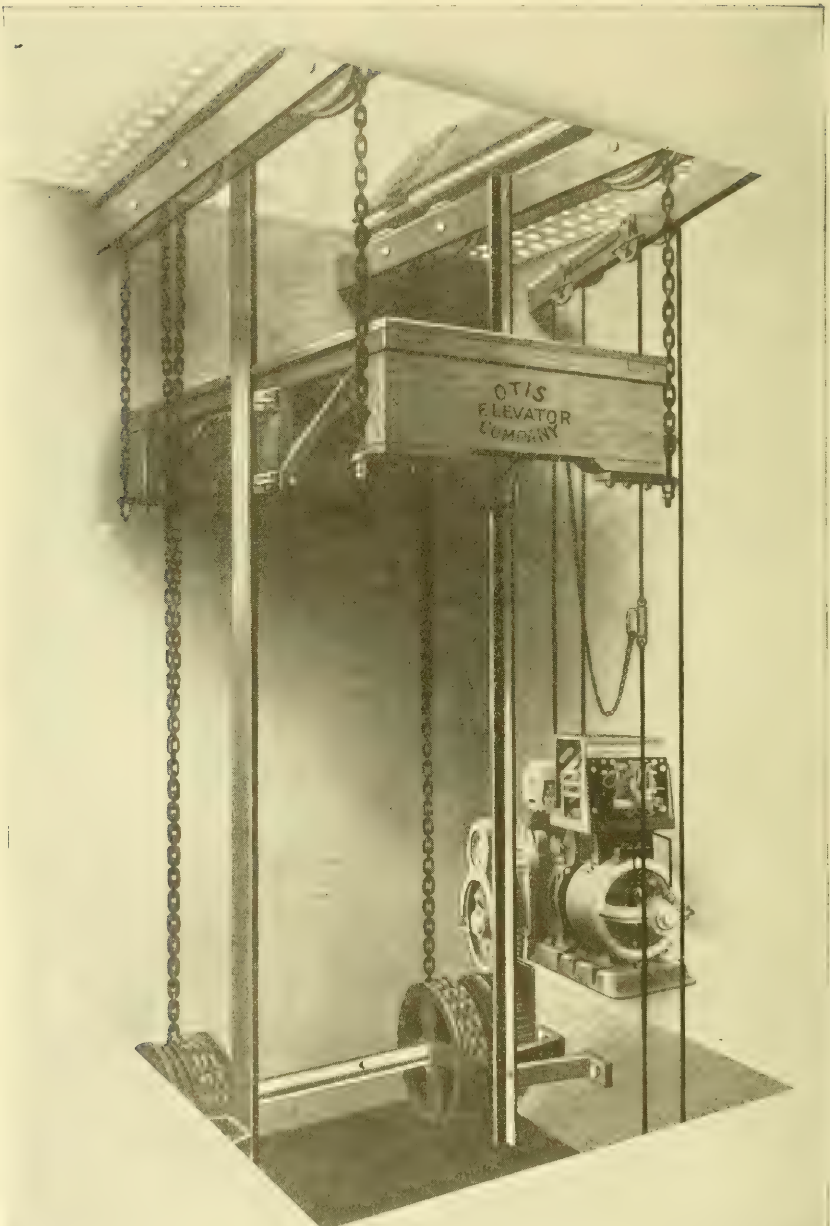


Fig. 172. Otis Elevator Sidewalk Lift
Courtesy of Otis Elevator Company

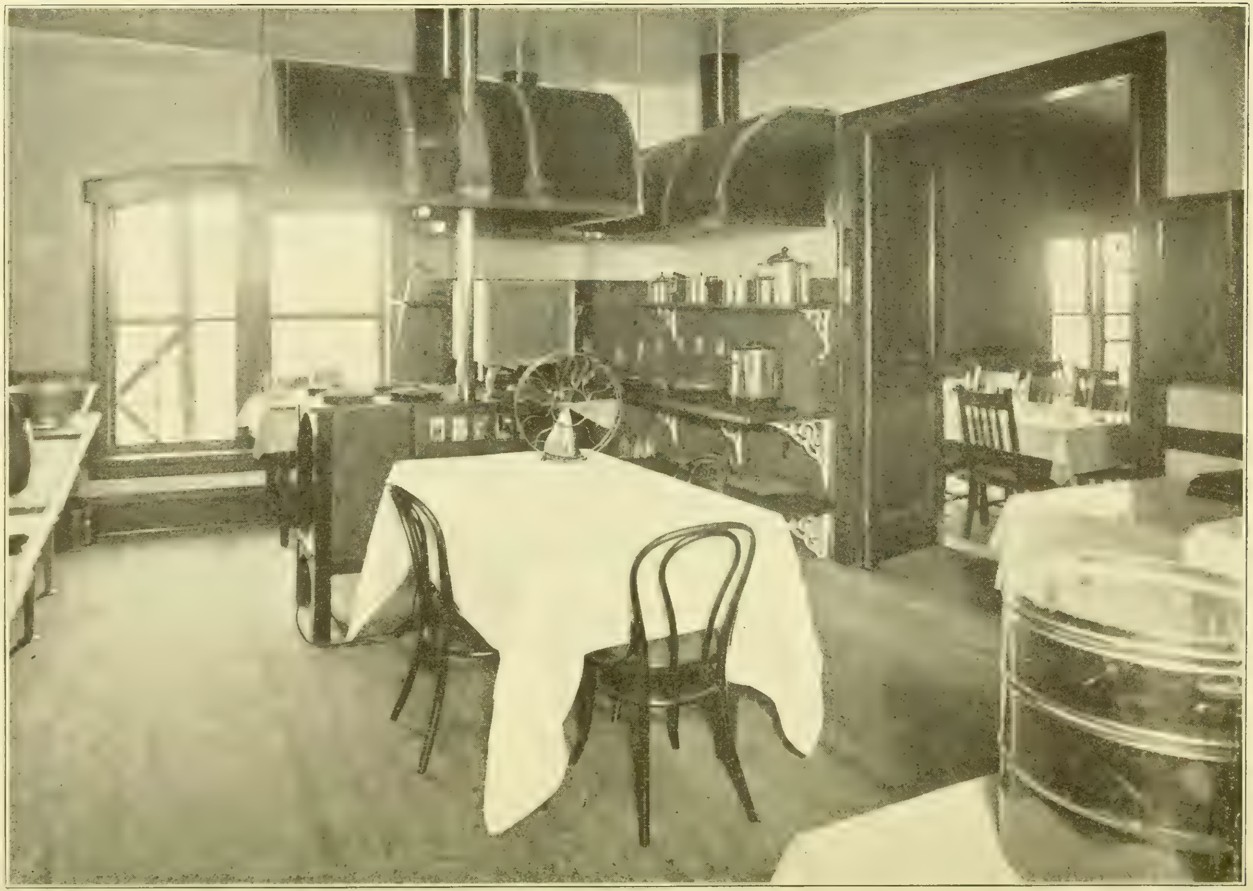
"one-to-one" type, and a powerful brake is provided which is used only in emergencies. This brake is applied by means of a lever and weight, which are held out of service by a latch or bolt arranged to be tripped by another centrifugal governor when a dangerous speed is attained. The motor used runs at a higher speed than that used with the "one-to-one" engine, but at a lower speed than that used with the worm and gear.

Difficulties with Traction Types. With all traction elevators, no matter whether driven through the medium of gearing or directly from the armature shaft, there is a danger of slippage of the cables on the driving drum, especially if the cables become greasy. This slippage is most noticeable when the operator endeavors to stop in descending with a heavy load. This is especially true if the speed is high and the attempt is made to stop quickly, the car sometimes sliding past the landing even to the extent of a story or two; should this occur (and it has done so in many instances) at the lower landing, a very unpleasant jar results.

The cause of this slippage is usually insufficient counterpoising, or if the building is at least twelve stories, it is probably due in a measure to the preponderance of weight on the car side of the drum, owing to the fact that the cables hang almost wholly in the hatch above the car. The remedy in such a case is the use of the chain counterpoise.

Miscellaneous Elevators. *Single-Belt Type.* There are other forms of electric elevators which are occasionally used. One of these, known as the single-belt elevator, consists of a worm-geared machine, hung from the ceiling of the room and adjacent to the hatchway, and driven by a motor through the medium of a leather belt. No countershaft is used, but the motor, which is reversible, is also located on, or hung from, the same ceiling at a distance of eight or nine feet from the winding gear, and drives it by means of the above mentioned belt. The motor is provided with a sliding base frame and screws in order to compensate for stretch of belt; the controller is attached to the frame or casing of the winding gear and is properly wired to the motor.

Sidewalk Type. Another type is the electric sidewalk or basement lift, Fig. 172. It is heavily built and is driven by a small electric engine.



COMMONWEALTH EDISON ELECTRIC KITCHEN AT FISK STREET STATION

Courtesy of Commonwealth Edison Company

ELECTRIC HEATING

Introduction. The popularity of electric heating apparatus has been growing steadily, not only because of the greater acquaintance with and confidence in these devices on the part of the general public, but also on account of the improvement in design and quality of manufacture. The busy housewife finds every domestic utensil now on the market a blessed relief from routine methods and a delight to her cleanly soul. The industrial worker finds the electrical appliances so much more dependable and uniform in their action than their mechanical forerunners as to materially increase his speed and efficiency.

This article treats of only the low amperage appliances such as are used with 110-volt lighting circuits; those devices requiring high amperages will be found adequately treated in the articles on Electric Welding and Applied Electrochemistry.

THEORY AND PRACTICE

Action of Current. An electric current passing through a conductor creates heat within this conductor. This heat may be so slight as to be unnoticed or it may be so intense as to melt the conductor, proving that the temperatures which are possible by this method may be very high. In the electrical appliance not designed for heating purposes, any heat developed in the circuit becomes a dead loss, and hence the carrying capacity of the circuit must be such as to keep these heat losses as low as possible. When, however, the appliance is created with the idea of utilizing this electric heat, the matter of design is found to be an all-important item. Many experiments and researches were necessary before the appliances which were built would give satisfaction.

This heat generated in a conductor depends in general upon three factors: the current, the resistance, and the time. If we bring these quantities into a formula, we have:

$$H=AI^2RT$$

where H is the heat generated; I is the number of amperes of current in the circuit; R is the resistance expressed in ohms; T is the time in seconds, minutes, or hours; and A is a constant of proportionality. We see from this expression that the heat changes directly as the square of the current, directly as the first power of the resistance, and directly as the first power of the time. In other words, when we increase the current, say, from 3 amperes to 6 amperes, all other conditions remaining the same, we have increased the heat generated not two but four times. Our first endeavor, consequently, would be to increase the current strength as much as possible in order to obtain a large amount of heat, but unfortunately there are very definite limits to this plan on account of the cost of the current. Another logical step would be to increase the resistance. This is easier to accomplish because material is the only consideration, with perhaps a slight extra cost of manufacture. The limit in this case is the amount of current which the conductor can carry without melting. The third factor to be considered is the time. The longer the current flows in the wire, the higher will be the temperature. But even here are limitations of practical consequence. If, for example, we want one quart of water brought to the boiling point, a time limit of five minutes would be considered admissible; but nobody would buy an apparatus which required an hour to bring one quart of water to the boiling point. The time limits are determined almost entirely by practice.

The designer of electric heating apparatus must try to bring the three quantities, current, resistance, and time, into such relations to each other that they will give the highest possible efficiency. The current, being a persistent item of expense, must not be raised to any large amount, and, therefore, the designer's attentions are usually directed towards increasing the resistance. Working to this end, conductors consisting of special alloys of high resistance have been manufactured and they are embedded in special material so as not to burn out easily.

Heating Methods. According to FOSTER'S "Electrical Engineer's Pocket-Book", we may distinguish eight different methods of heating a metallic conductor by means of the electric current:

(1) Exposed coils of wire or strips
(2) Wire or strips of metal embedded in enamel
(3) Wire or strips of metal embedded in asbestos and other insulating material

(4) Wire embedded in various insulating compounds
(5) A film of metal
(6) Sticks of metal
(7) Metals in the form of powder or granules
(8) Incandescent filament in vacuum

Exposed Coils of Wire or Strips. These coils may be wound around any insulating material or they may be entirely surrounded by air.

Wire or Strips of Metal Embedded in Enamel. The Simplex and General Electric Systems are developed according to this method. In the former, high resistance wires are embedded in an enamel consisting of special constituents which are very carefully mixed. The insulation resistance varies from 40 megohms when cold to 1000 ohms at 400° C. The enamel, which is fused to the iron, is not brittle or glass-like, and will not flake or chip off of the metal. In manufacturing, several coats of enamel are applied and fused separately. In one of the operations, all the resistance wire is exposed for examination after it is fixed in place. By this inspection it is seen that the wires occupy their proper place to insure proper insulation throughout. Succeeding operations cover and seal-in the resistance wire. The terminal leads of larger cross section than the resistance wire are attached to the resistance and the joints are covered with enamel, leaving only the terminals projecting. The advantage of this method of construction is that the resistance becomes integral with the apparatus to be heated, and being embedded in the iron, conduction of heat is more rapid. The General Electric System employs spirally wound "Climax" resistance wires, insulated from the surface to be heated by quartz enamel.

Wire or Strips Embedded in Asbestos and Other Insulating Material. A method employed by the General Electric Company is to use German silver wire flattened into a ribbon, and wound edgewise in a spiral. The spirals are insulated at the turns by dipping them into a bath of insulating cement. They are then squeezed together and brought to the form of a cartridge, which is slipped into a German silver shell with only .01 inch of mica between the ribbon and the shell. The heat, passing through the mica, is conducted to the outer shell and thence to the surface to be heated.

Metal Films. The Prometheus System employs very thin strips of mica on which thin films of gold or platinum are painted. The metals are brought to the form of powders, mixed with a flux, and then painted on the mica in a very thin layer. The painted strips are subjected to high temperatures and are usually covered with another strip of mica to prevent injury.

Sticks of Metal. The Parvillé System employs rods consisting of metallic powder, mixed with a fusible clay, compressed under high pressure and at high temperature.

Metals in the Form of Powder or Granules. Another type of resistance is in the form of powder or granules, for which a special patented substance called "Kryptol" is used. It consists of a mixture of graphite, carborundum, silicate, and clay in a granular form.

ADVANTAGES AND DISADVANTAGES OF ELECTRICAL APPLIANCES

Sanitation. The absence of any flame, poisonous gas, smoke, or dust makes the use of electric heat especially valuable from the standpoint of sanitation and hygiene. If we consider the dangers connected with coal and gas heat, which we unconsciously encounter, it is really strange that electric heat is not employed to a larger extent. One open gas cock may kill a family or put them on the sick list for a long time, and dirt which accumulates around all our heating apparatus in common use is always a source of danger.

Readiness. In using coal heat we have considerable work before the heat is obtained. The conditions are better when we have gas at our disposal, but even in this case the convenience is not as great as with electric heat which is available at any instant simply by turning a switch.

Convenience. Availability at an instant is one of the cardinal virtues of electrical devices. At any time, day or night, we have a sufficient source of heat at our disposal, without delay, without any dirty work to be done; we have what we want in a second, and there is no handling of ashes or fuel. An electric heater may be applied directly to the spot where the heat is needed, a requirement which virtually excludes the use of gas and coal. The control of the heat is absolute; an electric oven will turn out one loaf of bread like another and it is not necessary to employ skilled help.

Less Danger of Fire. Freedom from the danger of fire is one of the most important advantages of electrically-heated apparatus. The absence of matches and open flames lessens the danger of fire practically to zero. No garment can catch fire by coming accidentally in contact with the heating apparatus. If we remember the danger in the use of gas, gasoline, or other inflammable material, we shall clearly understand that the preference belongs to electricity.

Cost. The greatest drawback to the extensive use of electrical appliances is the high first cost, and the cost of renewals and operation. There is no question that at the present time several electrical appliances can be used with real economy, but on the other hand there are a number of domestic applications where the possibilities cannot be used to their full extent on account of the high cost involved. That we are rapidly gaining ground is sure and it is hoped that the difficulties which we have still to overcome will disappear in the near future.

Comparison with Other Methods. Admitting that electric heating is expensive, it may be instructive to analyze the cost and efficiency of a gas heater, a coal burning grate, and an electric heater. Assume a gas stove of good design located in the open room and burning, say, 5 cubic feet of gas per hour. Such a stove will give an average of 3500 B. t. u. The burning gas will consume considerable oxygen, however, and unless sufficient fresh air from the outside is provided the ventilation will be bad. By connecting the stove to the chimney or using a regular gas grate, the ventilation will be improved, but to supply the same amount of heat as that given above, the gas consumption must be increased to 10 cubic feet. Assuming a price of $1.00 per 1000 cubic feet of gas, the cost of fuel for the arrangement would be one cent per hour.

In the case of coal grates, the loss of heat up the chimney is possibly somewhat more than with the gas grate, but the expense is very much less—probably about a fifth.

In the case of electric heaters, a "four glower" stove may be taken as a standard because it will use about 1000 watts per hour from which we may obtain 3412 B. t. u. This heater, therefore, is in every way comparable with the gas heater, but does not exhaust the air of its oxygen. Of course, a proper amount of ventilation must still be provided, but the heat which is supplied has the advantages of cleanliness, instant availability, and lack of any effect upon the air of the room. This amount of electrical energy, however, viz, 1 kilowatt hour, costs about 10 cents as compared with 1 cent for gas. By the use of tungsten filament glowers this can be cut considerably, but in any event the cost is considerably greater than for gas. Evidently then electric heating must be adopted on the grounds of utility rather than economy.

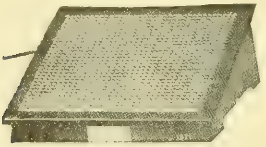


Fig. 1. Simplex Electric Foot Warmer

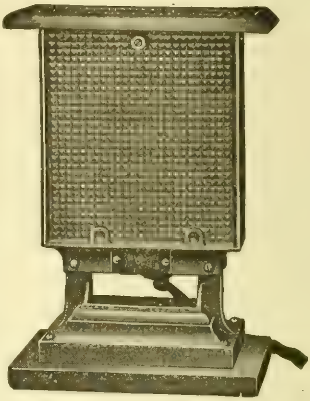


Fig. 2. Simplex Radiator for 110-Volt Circuit

The economic problem for the large heaters is the same as for the small ones, but, by the same token, the advantages are just as pronounced. These heaters are especially desirable for heating rooms on chilly mornings and nights in spring or autumn. Attention should be called, however, to the fact that a stove or heater of the above capacity connected to a 110-volt circuit needs 9 to 10 amperes and cannot be connected to an ordinary lamp circuit which will carry a maximum of only 6 amperes. The installation of separate circuits will, of course, raise the cost to some extent.

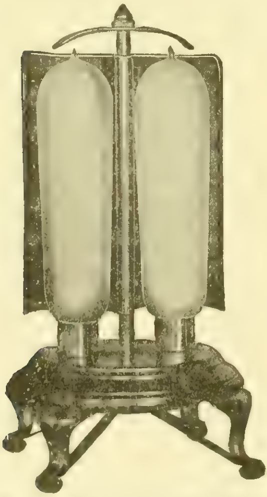


Fig. 3. General Electric Twin-Glower Stove

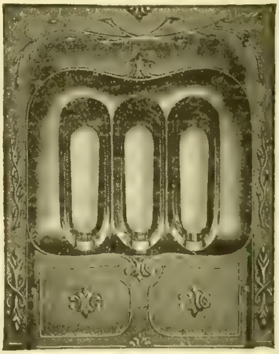


Fig. 4. General Electric Grate with Three Glowers

And yet with all these disadvantages, we find on the market at present many small electrical devices which are designed and manufactured to supplement and make the domestic labors lighter. Used in this way they have proved of considerable value.

COMMERCIAL APPLICATIONS

DOMESTIC APPLIANCES

Electric Foot Warmer. Fig. 1 shows a little device which is very useful where the floor of a room is cold, or where invalids need a uniform and moderate heat. This heater is designed for continuous use without reaching too high a temperature. Its power consumption is only 50 watts, not more than is required by a carbon incandescent lamp. Larger ones consuming 100 to 400 watts with three heat regulations may be procured.

Electric Radiator. A small radiator designed for 110- to 220-volt circuits is shown in Fig. 2. It has one or three heating steps, consuming from 800 to 1000 watts. Fig. 3 shows a so-called "twin glower" of the luminous type. It consumes 500 watts and is designed especially for lighting circuits. A larger type for permanent installation as an electric grate is shown in Fig. 4. A section of a typical heating unit one-half its actual size is given in Fig. 5. These small heaters are to be recommended for the nursery, the sick room, and as a substitute for the old-fashioned fireplace. There is no danger of fire, nor any soot, dirt, or bad air.

Cooking Apparatus. In cooking utensils the heat is supplied in two ways: (1) by a plate on which the dish is placed, which is made hot by a special heater inserted into the dish; or (2) the heating unit may be connected solidly with the dish, forming

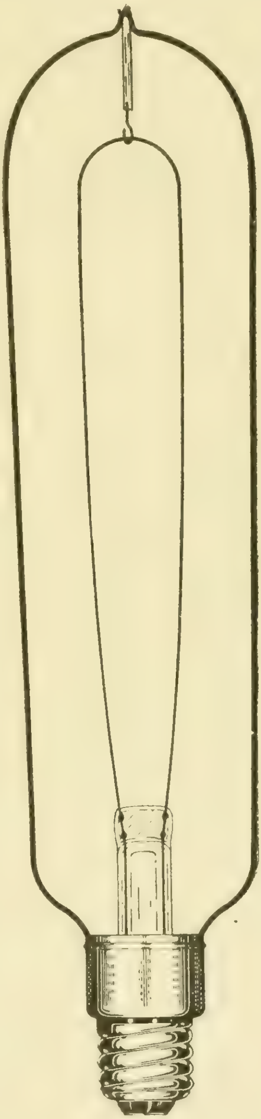


Fig. 5. Section of Glower One-Half Size

Courtesy of General Electric Company

one piece. A few representative types of these utensils will serve to illustrate the many uses of electricity in cooking.

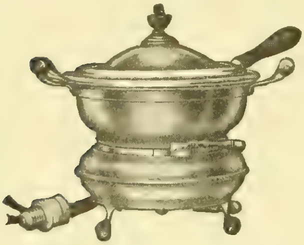


Fig. 6. Simplex Chafing Dish

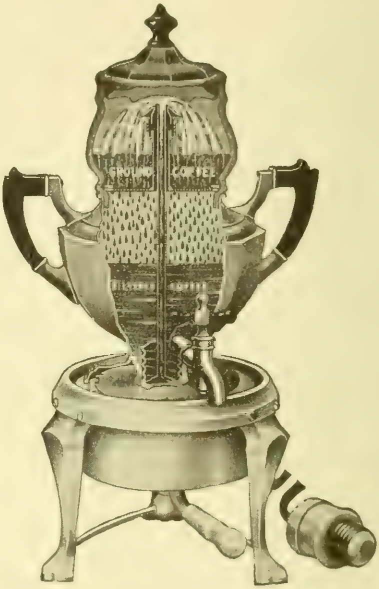


Fig. 7. Simplex Coffee Percolator

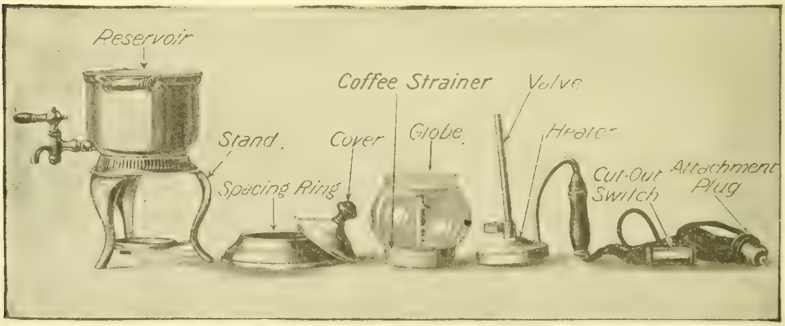


Fig. 8. Disassembled Coffee Percolator
Courtesy of Westinghouse Electric and Manufacturing Company

The Chafing Dish. Fig. 6 shows a chafing dish, consisting of an electric stove and food and water pans either of which can be clamped to the stove by a simple device which provides perfect heating contact. The stove resistance coils are fused to the iron plate that forms the top, thus insuring direct transmission of heat. A regulating switch gives three different heating steps.

Coffee Percolator. An electric "spray coffee urn", or "percolator", is illustrated in Fig. 7. At the turn of the switch the electric stove under the urn supplies the necessary heat for boiling the water. All stoves are supplied with regulators giving three heating steps. The power consumption is 500 watts. Fig. 8 shows the different parts of another type of percolator. The power consumption of this apparatus is 350 watts.

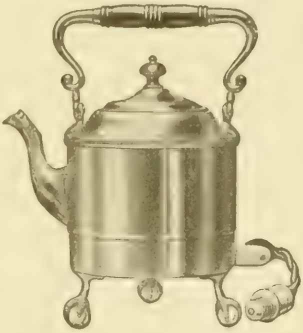


Fig. 9. One-Piece Teakettle
Courtesy of Simplex Electric Heating Company

Teakettle. Fig. 9 illustrates a quick heating teakettle. It has a special safety device which breaks the circuit in case the kettle boils dry, thus avoiding any waste of power and possible injury to the kettle. Fig. 10 shows the components of a tea samovar. It will be noticed that Fig. 9 is in one piece, while

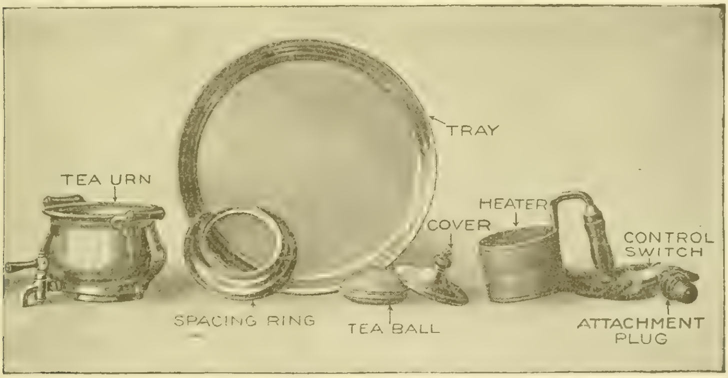


Fig. 10. Components of Tea Samovar
Courtesy of Westinghouse Electric and Manufacturing Company

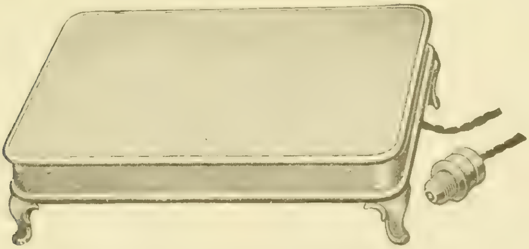


Fig. 11. Electric Food Warmer
Courtesy of Simplex Electric Heating Company

Fig. 10 consists of the samovar proper and the heater which is inserted into the kettle.

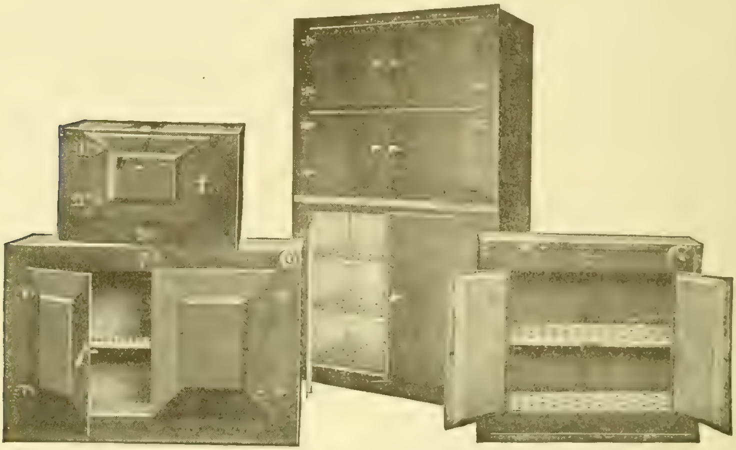


Fig. 12. Simplex Plate Warmers of Various Sizes

Food Warmer. The food warmer shown in Fig. 11 is intended to be used to keep meats or vegetables warm with no fear of injury to china or plate. It is manufactured in sizes consuming from 300 to 600 watts. The top is removable from the frame, insuring simple cleaning and polishing if necessary.

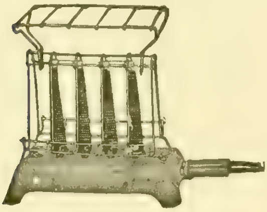


Fig. 13. General Electric Radiant Toaster

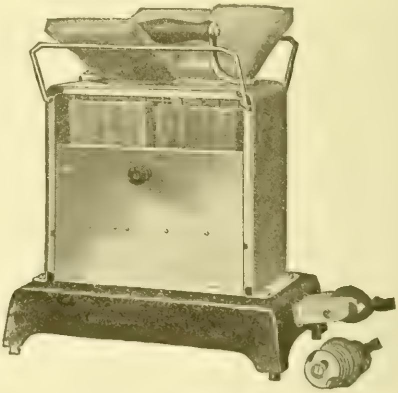


Fig. 14. Simplex Toaster

Fig. 12 shows several plate warmers of sizes convenient for any niche in kitchen or pantry. They are provided usually with two shelves and have a temperature control of three heating steps. They consume from 200 to 1200 watts.

Breakfast-Room Toaster. A so-called "radiant toaster" is shown in Fig. 13. The advantage claimed for this type is that the whole process may be watched and toast may be made to suit the individual tastes. Another type is shown in Fig. 14. On each side is a door swinging outward and downward so as to permit the placing or removing of bread without danger of burning the fingers. When toasting, the doors are closed in order to confine all heat within. The power consumption is 500 watts. Fig. 15 is a toaster stove of the horizontal type.

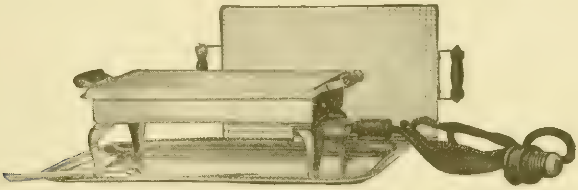


Fig. 15. Westinghouse Toaster Stove of the Horizontal Type

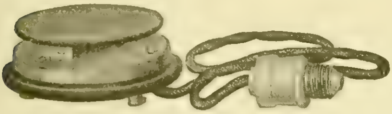


Fig. 16. Four-Inch Single-Heat Disk Stove

Plate or Disk Stove. Disk stoves are useful for a great variety of purposes—for light cooking of all kinds, for making tea, heating water, etc. Fig. 16 is a single-heat 4-inch stove consuming 200 watts; Fig. 17 shows a 6-inch type of the same manufacture.

Milk Warmer. Milk which is heated in the usual way is liable not to warm uniformly, the parts coming into close contact with the source of heat becoming hottest first. To avoid this the "nursery milk warmer", as illustrated in Fig. 18, is manufactured, consisting of a coil tube heater that surrounds the glass, thus heating the milk evenly and quickly. Its power consumption is 440 watts.

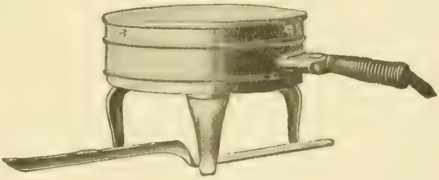


Fig. 17. Six-Inch Single-Heat Disk Stove

Oven. The advantages of the electric oven, Fig. 19, lie especially in the even distribution of the heat and the absence of any drafts. There is nothing to equal it except the old-fashioned brick oven. Double walls are provided, filled with asbestos, and when the door is closed we have practically an air-tight box. Three different degrees of heat may be applied with a power consumption of 1300 to 2400 watts.

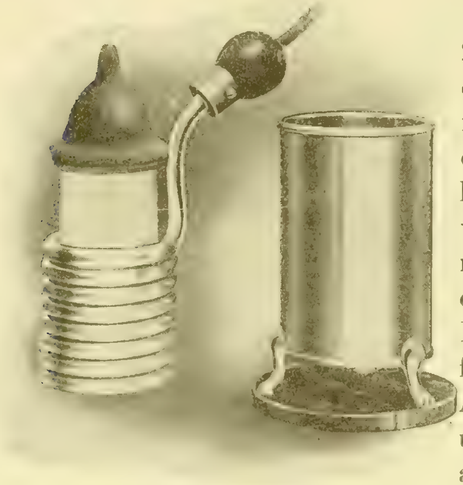


Fig. 18. Simplex Milk Warmer

Range. The range, Fig. 20, brings together in a convenient form all of the necessary appliances for cooking by electricity. It has an oven broiler, a toaster, three or four separate heaters and the proper cooking utensils for them. It is a perfect substitute for a gas or coal stove. Any of the utensils can be used separately and they are always ready.

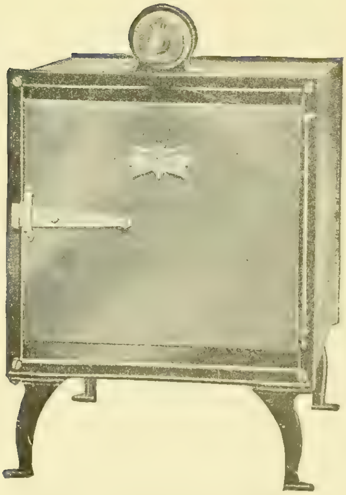


Fig. 19. Simplex Electric Oven

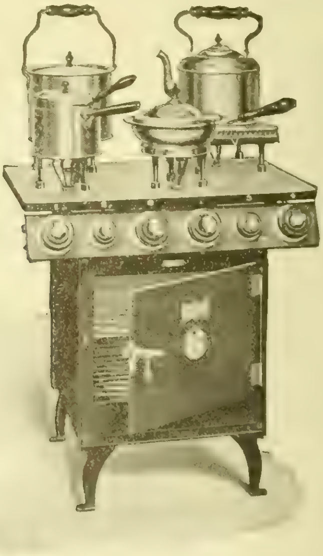


Fig. 20. Simplex Electric Range

Electric Irons. Electric irons of great variety are on the market, and their usefulness is fully appreciated by the busy housewife. Fig. 21 shows an assembled view of an electric iron, and Fig. 22 the separate parts. The heater consists of a thin metallic ribbon wound around a plate of mica. When assembled in the iron, it is protected above and below by a plate of mica and is clamped between the shoe and the storage plate under high pressure. All the heat generated passes directly into the storage plate and the shoe, and is delivered with very small losses to the ironing surface. The total weight of an iron for domestic use is five or six pounds and the power consumption 380 to 500 watts. Fig. 23 shows an iron of another make. In this type the heater covers the entire area and is sealed to it so that the bottom of the iron and the heater are one.

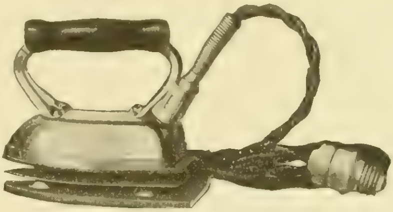


Fig. 21. Westinghouse Electric Iron

Another type of iron which is much used is the electric curling iron, Fig. 24. It is particularly valuable in traveling, as it can be plugged into any standard circuit in hotel, steamship, or Pullman car.

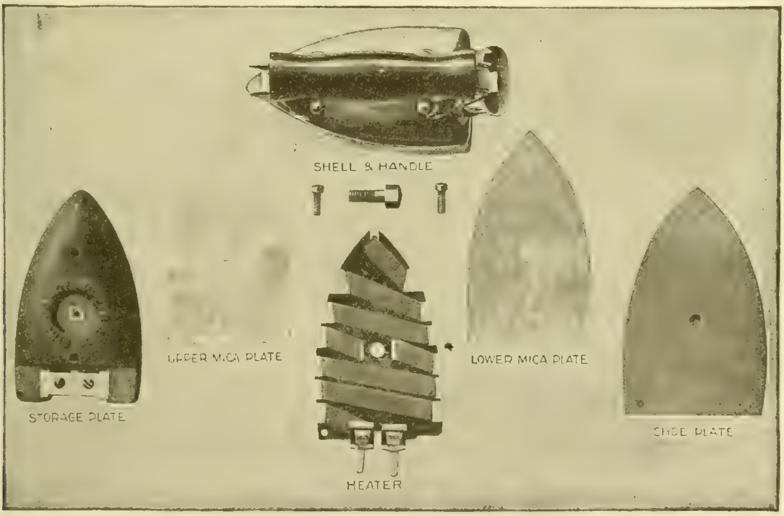


Fig. 22. Disassembled Electric Iron Showing Construction
Courtesy of Westinghouse Electric and Manufacturing Company

it does not need to be connected to steam or gas pipes, it can be plugged into any circuit like an electric light. Fig. 26 illustrates a patented pot consisting of three parts: the glue pot, the spiral tube coil heater, and the water vessel. The upper part of this vessel forms a reservoir which feeds water into the well as fast as it evaporates. The well is, therefore, always full, but holds only a little water at a time, thus assuring quick heating and small current consumption. Fig. 27 shows a smaller pot which is useful where glue in small quantities or of more than one kind is used by the same workman.

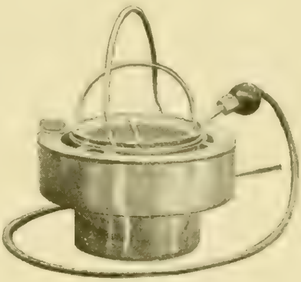


Fig. 26. Electric Glue Pot with Reservoir
Courtesy of Simplex Electric Heating Company

Soldering Irons. The use of electric soldering irons is recommended especially for intermittent work. The Simplex Company furnishes with its irons an automatic controller which keeps the temperature of the tools within the desired working limits. This controller prevents overheating when the iron is idle. Automatic handle switches may also be had which will instantly cut off the current if the iron is laid anywhere except on the stand provided. The power consumption varies from 75 to 450 watts.

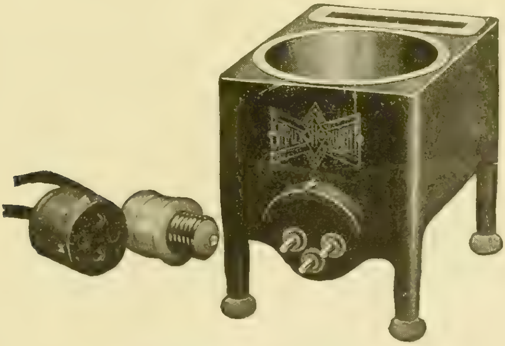


Fig. 27. Small Glue Pot
Courtesy of Simplex Electric Heating Company

Laundry and Tailors' Irons. The requirements for laundry and tailor's irons differ somewhat from those for domestic irons. They are more continuously in use, they must serve a greater variety of purposes, and they must stand rough handling. It is important, therefore, to locate them permanently and to surround them with all possible safeguards. Many patterns are on the market provided with automatic switches which cut off one-fourth of the current when idle, thus avoiding overheating and still keeping the irons warm. The Simplex iron body consists of two parts: a solid bottom and a hollow top. To the upper side of the bottom, the resistance wire is fused and the hollow top insures slow heating of the top. Fig. 28 shows a "smoothing iron" with automatic and hand regulator; the latter permits control of the heat of the iron when in use. A "drag iron" is illustrated in Fig. 29; it is adapted for use in laundries for ironing tablecloths or other large pieces. It weighs 30 pounds and is dragged by means of the spade handle over the work; a second handle is used for lifting only. The use of the connecting cord is an inconvenience, and in this type the manufacturers have

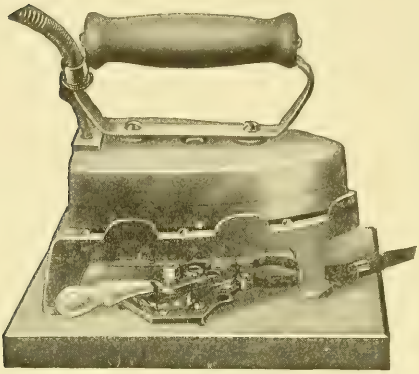


Fig. 28. Simplex Smoothing Iron with Automatic and Hand Regulator

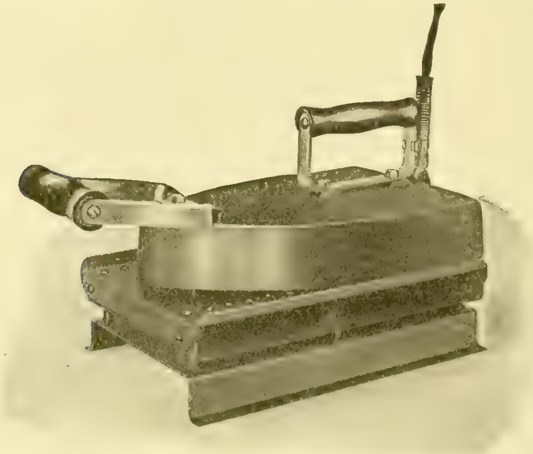


Fig. 29. Westinghouse Drag Iron

avoided this difficulty by constructing a special stand, Fig. 30, on which the iron may be heated when not actually on the cloth. The iron is merely placed in position and the current turned on by means of a switch.

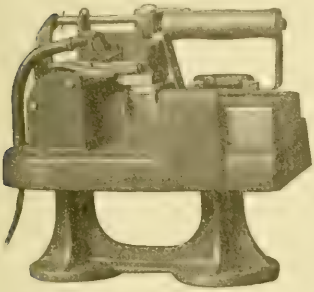


Fig. 30. Westinghouse Electric-Iron Stand

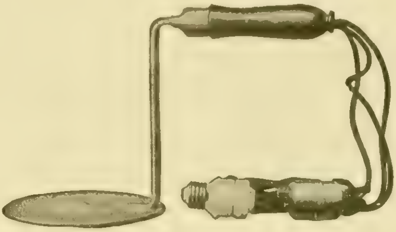


Fig. 31. Westinghouse Immersion Heater, Disk Type

Immersion Heaters. Immersion heaters are useful for many purposes, such as water and oil heating, glue and paraffin melting, steam generation, etc. The essential feature is that they are not connected permanently to the containing vessel but may be removed at any time for cleaning and other purposes. Being entirely immersed in the substance to be heated they are very economical, no heat escaping except through the substance to be heated. Two distinct types are illustrated, the disk type, Fig. 31, and the bayonet type, Fig. 32.

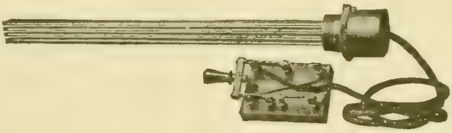


Fig. 32. Westinghouse Immersion Heater, Bayonet Type

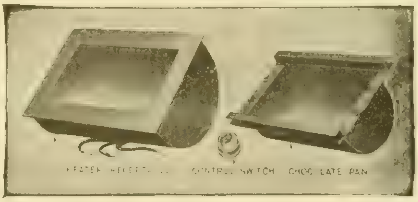


Fig. 33. Westinghouse Chocolate Warmer

Chocolate Warmer. A chocolate warmer is a very useful apparatus for candy manufacturers. The chocolate may be kept at a uniform temperature, thus enabling the operator to carry on the work with greater certainty. The warmer consists of two parts: the chocolate pan of sheet metal and the hermetically sealed metal receptacle containing the heating element, Fig. 33. Fig. 34 shows the warmer mounted in a table.

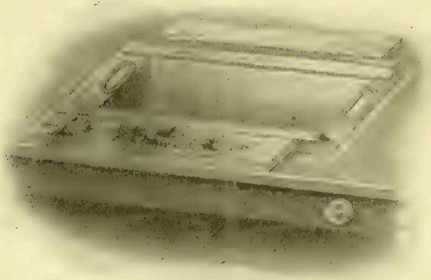


Fig. 34. Chocolate Warmer, Set in Table

This short enumeration of a few of the industrial applications will give some idea of the extent of the industrial field. Progressive manufacturers are constantly designing new devices and putting them on the market. We are just at the beginning of the development of this type of electrical apparatus.

MEDICAL APPLIANCES

Attention has been called to the employment of electric heating apparatus on account of the sanitary conditions which it makes possible. It is, therefore, no wonder that the medical profession greatly favors electric heat. A few of the many small appliances for the office or the home are here discussed.

Heating Pad. The electric heating pad, Fig. 35, for household or hospital use is intended as a substitute for the hot water bottle, over which it presents many advantages. It is more comfortable and pliable, adjusting itself to any part of the body. It will not cool off, but will keep the correct temperature as long as wanted. It is soft and flexible, covered with eiderdown, can be used in any position, and is so light that it is never uncomfortable. The maximum temperature is limited automatically to 180° F. There may be a regulating switch giving three different heating steps. The power consumption is from 13 to 100 watts.

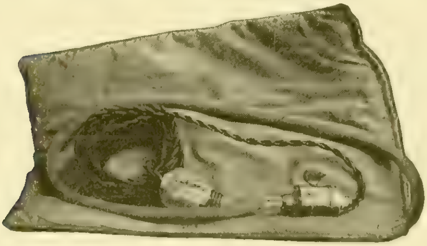


Fig. 35. Westinghouse Electric Heating Pad

Instrument Sterilizer. One of the best applications of electric heat is for the sterilization of surgical or any other instruments, Fig. 36. Automatic cut-outs may be attached which will act in case the vessel is allowed to run dry.

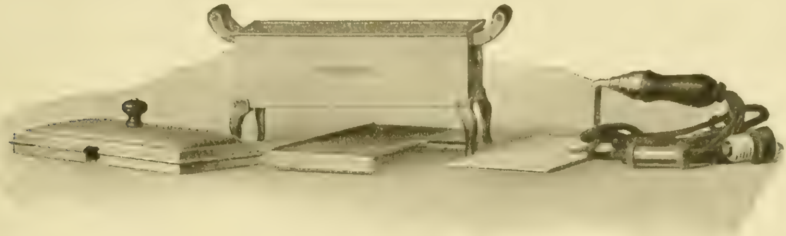


Fig. 36. Disassembled Electric Instrument Sterilizer
Courtesy of Westinghouse Electric and Manufacturing Company

Electric Blanket. The National Electric Company has brought on the market an electrically-heated blanket which not only makes outdoor sleeping in the winter time agreeable and possible for everybody, but also is a great comfort for weak and sick people. The blanket is very light and flexible, and weighs less than half as much as the lightest comforter or blanket. It has a soft covering of satin and can be easily folded. The cost of operation is low, the same as for an ordinary 16-c. p. lamp. The H. W. Johns-Manville Company manufacture under the name of "Electrotherm" all kinds of blankets for hospital use and for the operating table. Fig. 37 shows an operating blanket and Fig. 38 shows an "Electrotherm" cap.

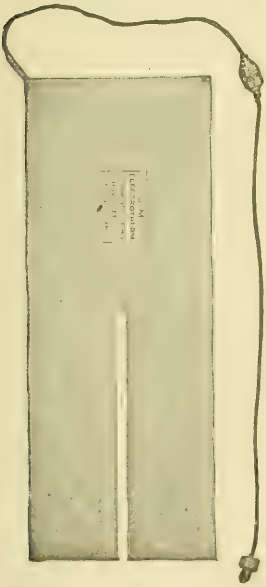


Fig. 37. Electric Operating Table Pad
Courtesy of H. W. Johns-Manville Company

Electric Crematories. In crematories in Pasadena and Oakland, California, electric heat is applied to the body in the casket, raising the temperature inside of an individual retort to 2000 degrees and completely incinerating the body after two hours.

WATER-HEATING APPARATUS

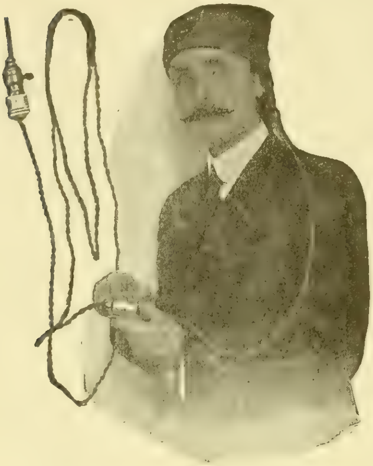


Fig. 38. "Electrotherm" Cap

Electric heating has no more important application than to the heating of water, and the construction difficulties which present themselves are greater than for any of the devices already mentioned. We usually want hot water in large quantities for cooking, cleaning, and other purposes, and we want it quickly. There are several methods which more or less answer the requirements just outlined.

Immersion Coil. One type of water heater, consisting of coils to be immersed in the water, is shown in Fig. 39—a very efficient type, as it has been already shown that there are practically no heat losses with this arrangement. It is made in several sizes with a threefold heat regulation, and may be used in connection with any vessel of proper size. The circulation water heater, shown in diagram in Fig. 40, is intended to take the place of the common kitchen boiler. It has about the same capacity, outlines, and general arrangement, but it differs, of course, in the fact that the electric current supplies the heat. This electric heater may be attached to any of the usual types of kitchen boilers. The water circulates from

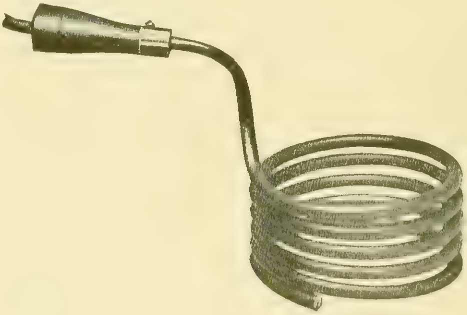


Fig. 39. Simplex Electric Water-Heating Coil

the bottom through the heater and is discharged at the top of the boiler at about 180° F.

The Westinghouse Company gives the following formulas for calculating the time necessary to heat any amount of water to any desired temperature:

$$t=\frac{146n\ (T_1-T_0)}{ew}$$

$$t=\frac{17.5p\ (T_1-T_0)}{ew}$$

where t denotes the time in minutes; n the number of gallons; T_0 initial temperature of water; T_1 final temperature of water; w the number of watts; e the per cent efficiency; p the number of pounds of water. The efficiency of heating varies from 50 per cent for external heaters up to 95 per cent for immersed heaters, under the most favorable conditions.

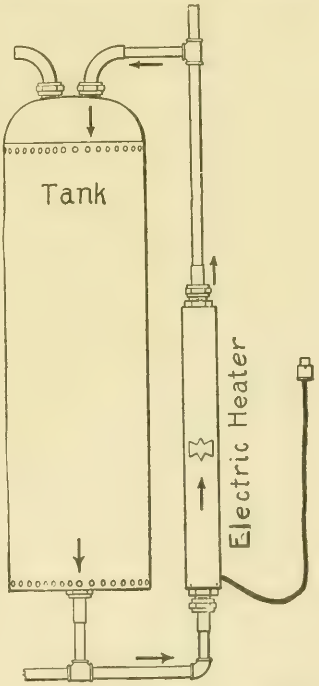


Fig. 40. Diagram of Electric Hot Water Plant
Courtesy of Simplex Electric Heating Company

Storage Systems. Ever since the development of electric heating apparatus began, it has been the aim to obtain electric power at a cheaper rate. Electric heating devices, considered as separate units, are practically perfect; and the utilization of the heat supplied to the heaters is as high as we can ever expect. The real reasons why their use is sometimes prohibitive are the losses in the power company's equipment between the coal supply and the electric generator, and the large capital investment for the necessary machinery. To cut down these expenses somewhat, the power plants should have a more constant load factor; that is, the installed machinery should be in use approximately through the whole day. At present a great number of machines must be kept for the greater part of the time in idleness, waiting for the so-called "peak hours"—the hours of greatest demand. Electric light is still the greatest consumer of electric energy and, as soon as the darkness comes, all of the reserve electric machines are put to work for some hours until the rush is over. This reserve machinery with its heavy capital outlay is in operation, therefore, only two to four hours daily, and during the balance of the time is not earning anything. It is desirable, therefore, to procure a constant load for the power plant, because it would then be possible to furnish the power at a much lower rate. One of the plans suggested is for the companies to provide current at a much cheaper rate during the day for heating large quantities of hot water for evening use. Several hot water storage tanks have been designed with the ultimate idea of decreasing by this means the price of electricity per kilowatt hour.

RESISTANCE WIRE

Several companies are manufacturing resistance wire of high resistance, especially intended for electric heating apparatus. Table I gives the most important data on "Nichrome" wire as manufactured by the Driver-Harris Wire Company. This data is very useful in the designing of any kind of electric heating appliance, giving the really fundamental information.

EXPLANATORY

(1) The column headed "Gauge B. & S." gives the area of the wire of each gauge size in square and in circular mils, while the column headed "D." gives the diameter in inches of the gauge number written to the left in the first column.

(2) The column headed "S. F." gives the surface in square inches per lineal inch of the wire of each gauge size. These values are useful as a factor in estimating the probable working temperature of wires under conditions of extreme enclosure and pressure. They are not used in interpreting the balance of the table.

(3) The temperatures at the head of temperature columns will be attained under ideal conditions named. The figures following "A" give the carrying capacity, and those following "W" give the emissivity of a 110-volt unit when the ENTIRE unit is suspended in a straight horizontal line in free air at 20° C., while the figures following "L" give the length of the 110-volt unit in feet.

RULES

(1) The values given are correct, within the limits given, only under the ideal condition named.

(2) In practice the deviation from the ideal values will depend upon CONDITIONS, and must be taken into account. It may be very little in some cases but a great deal in others.

(3) In general, a unit for 110 volts of the length indicated will carry the current and dissipate the energy indicated (within a small per cent) under each temperature column, but the actual temperature attained may be different, and

TABLE I

PROPERTIES OF "NICHROME" WIRE

Published by Driver-Harris Wire Company.
Copyrighted, 1912, by Chas. P. Madsen, E. E.

Taken by permission of Author from Table entitled "PROPERTIES OF ROUND AND FLATTENED NICHROME WIRE".

Second Edition revised and corrected by observation at Lewis Institute with Standards of Temperature from U. S. Bureau of Standards.

Giving carrying capacity of round wires at corresponding temperature when suspended in straight horizontal lines in free air. Also length in feet of unit required for 110 volts and its total emissivity when suspended in a straight horizontal line in free air.

C. M.=circular mils; S. M.=square mils; D.=diameter of wires in inches; A=amperes of current; W=watts of electrical energy; L=length of wire in feet; S. F.=surface in square inches per inch; Specific Resistance=625 ohms per mil foot; temp. coefficient=.00044° C. approx.

Gauge B. & S.	DIMENSIONS				50° C. or 122° F.			100° C. or 212° F.			150° C. or 302° F.			200° C. or 392° F.			300° C. or 572° F.			400° C. or 752° F.			500° C. or 932° F.		
	C. M.	S. M.	D.	S. F.	A	W	L	A	W	L	A	W	L	A	W	L	A	W	L	A	W	L	A	W	L
10	10380	8150	.1019	.3201	7	770	254	11.3	1242	151.3	14.1	1550	118	17.1	1880	95.5	23.4	2575	67	28.1	3200	54.2	34.4	3780	43.6
12	6530	5129	.08081	.2539	5	550	224	8	880	135	10	1100	95	12.3	1352	83.5	16.9	1860	58.2	20.2	2220	47.5	24.8	2730	38
14	4107	3225	.06408	.2013	3.7	407	190	5.9	650	114.5	7.4	814	89	8.9	980	72.3	12.1	1330	51	14.7	1615	40.8	17.9	1970	33.1
16	2583	2029	.05082	.1596	2.8	308	158	4.4	484	96.5	5.5	605	75.5	6.5	715	62.5	8.8	968	44.2	10.7	1178	35.4	13.1	1440	28.5
18	1642	1275	.0403	.1265	2.0	220	140	3.2	352	84.5	4.0	440	65.8	4.8	528	53.7	6.5	715	38.0	7.8	858	30.9	9.5	1045	24.9
20	1021	802	.03196	.1004	1.53	168	114	2.43	267	69.2	3.05	335	53.7	3.57	393	45	4.8	528	32	5.78	638	26	7.0	770	21.1
22	642.4	505	.02535	.07964	1.1	121	100	1.75	192	60.5	2.2	242	46.8	2.66	292	37.9	3.56	392	27.1	4.28	472	22	5.10	561	18.2
24	404	317.5	.0201	.06315	.81	89	85.5	1.29	142	51.5	1.61	177	40.2	2.0	220	31.7	2.66	293	22.8	3.18	350	18.6	3.74	412	15.6
26	254.1	198	.0159	.05008	.60	66	72.5	.96	105.6	43.6	1.20	122	33.8	1.5	165	26.6	2.04	224	18.7	2.35	259	15.8	2.76	304	13.3
28	159.8	123.2	.01264	.0397	.47	52	58.3	.74	81.4	35.8	.93	102	27.5	1.13	124	22.2	1.50	165	16.04	1.77	195	13.2	2.06	227	11.2
30	100.5	79	.01003	.03151	.35	38.5	49.2	.55	60.5	30.1	.69	75.4	23.3	.86	94.6	18.35	1.13	124	13.4	1.33	146	11.1	1.57	173	9.25
32	63.21	49.7	.00795	.02498	.26	28.6	41.5	.41	45.1	25.3	.51	56.1	19.8	.66	72.6	15.03	.86	94.6	11.04	1.03	113	8.98	1.20	132	7.58
34	39.75	31.25	.0063	.0198	.18	19.8	37.8	.30	33	21.8	.39	42.9	16.3	.49	54	12.75	.65	71.5	9.22	.76	83.6	7.67	.91	101	6.3

usually much higher. (If a 110-volt unit of the length indicated under any temperature column be suspended in a straight horizontal line and exposed to free air only at 20° C. for its entire length, it will consume exactly the current and dissipate exactly the wattage indicated above its length, and the temperature attained will be within 10° C. of that at the head of temperature column, provided the wire is of standard specific resistance and size.)

(4) If the CONDITIONS are such that the energy cannot escape as freely as in air, then the temperature of the wire will be higher, in which case the current will drop proportionally to a small per cent of the temperature increase. Should the energy be able to escape faster, the reverse would be true.

(5) This rate of ENERGY TRANSFER is the function of a factor which must be determined EXPERIMENTALLY for each class of conditions in order to obtain the TRUE temperature rise under those conditions.

(6) Roughly, the difference in temperature attained in practice from that under ideal conditions may be estimated as follows:

Case 1. Open spirals and reflexes in open air, 10% to 25% higher.

Case 2. Complete enclosure 10% to 500% higher.

Case 3. When the unit is enclosed under a high pressure, the temperature rise may be the same as, or lower than, under ideal conditions, but if the devices be incorrectly designed there is danger of the conditions of Case 2 obtaining.

Note: It may be noted that the carrying capacity of resistance wires at a given temperature is not proportional to the cross section nor to the surface alone, but is a function of the surface, length, and curvature.

WELDING LIGHT SHEET-METAL TANKS AND CONTAINERS BY THE OXWELD PROCESS

This view is taken in the plant of one of the largest makers of such articles in the United States. The gas-welding process has been found to produce better results in quicker time and with more economy than any other method

Courtesy of Oxweld Acetylene Company

WELDING

INTRODUCTION

Welding an Ancient Art. The art of joining metals is one of the oldest known to man. Ever since the first cave dweller or half-monkey man hammered his first piece of iron or copper between two stones, the development of the art has gone forward, and will probably continue to develop as long as men use metals. The welding of iron is apparently as old as the production of that metal by man, for there is, in a temple yard of the ancient city of Delhi, India, an iron pillar nearly two thousand years old, which shows unmistakable evidences of having been welded. The shaft projects 22 feet above the surface of the ground, extends over 40 feet into the earth, and is about 16 inches in diameter. It was apparently welded into one piece from blooms of about 70 pounds weight each; the joints are as perfect as could be made with our most modern equipment, and yet they were forged by hand.

Conditions for Successful Welding. Strictly speaking, "welding" is the uniting or joining of two pieces of metal by hammering them together while they are hot enough to be plastic and the application of the term would thereby be limited almost entirely to work done in a blacksmith shop. But modern methods of obtaining high temperatures by gases and electricity have made possible the development of other and better methods of joining metals, many of which cannot be welded by hammering. Custom has applied the term "welding" to these also, although some of them are really brazed or soldered with metals of high melting temperatures. Any process by which cohesion between the molecules of the pieces to be joined is brought about may be called "welding".

Metals are most easily welded when in that degree of plasticity between the molten and the solid states; hence, those metals which remain plastic the longest while cooling are the easiest to weld. Originally welding was limited to such metals as iron, platinum, nickel, and gold but the recent development of high temperature systems has extended the field greatly. In fact, it is safe to say that every metal may be welded by some one or other of the modern methods. So recently as five years ago it was considered impossible to weld aluminum; but this is being done successfully today with the electric-arc system, using the graphite electrode, and practically every kind of alloy is also being welded by both the electric-arc and the gas systems.

Successful welding by any method depends almost entirely upon three factors: flow, cohesion, and temperature. The metal must tend to flow under great pressure, even if but to a slight degree. The surfaces of the pieces to be welded must tend to "wet" each other or cohere to an appreciable extent. The working temperature must be that at which the foregoing conditions are most prominent. The best welding condition for iron and steel exists within a limited range of temperature only and, when in this condition and at this temperature, they possess the property of expanding when cooled and contracting when heated. Therefore, modern welding systems are designed to take advantage of these well-known laws in the best and most economical manner, or else they are not considered commercially desirable and will, therefore, soon be abandoned.

It is for the purpose of describing in a general way these systems and their applications that this book has been compiled and it is our desire that all students of the art of welding may profit to the highest degree through their study of this subject. The field is expanding rapidly and great financial gains should be possible to the well informed during the next few years.

METALS AND THEIR NATURES

Iron and steel are the most useful and the most used metals we have and, since steel is merely iron with the addition of a small percentage of carbon and a few other elements, we will consider iron first.

Iron. Iron is made by taking iron ore, placing it in a furnace with fuel (coal, coke, or charcoal) and a suitable flux (usually limestone), and then melting it with the assistance of a forced draft until the ferrite in the ore is reduced to metallic iron. This is then run out into molds to form the "pig iron" of commerce. If this pig iron is again melted in a cupola and cast into molds of various shapes, it is called "cast iron" and is the material so largely used now for machinery and other articles.

Cast Iron. Cast iron is hard and brittle and granular in composition, because it contains so much carbon. This latter substance has come from the fuel used in melting the iron and the carbon content can be varied to suit requirements by "burning" it out. This is done by forcing a strong blast of heated air through the iron while it is still molten, causing the oxygen in the air to combine with the carbon and carry it off in the form of carbonic-acid gas, (CO_2). Charcoal makes the best fuel for use in smelting because it is so free from sulphur and other impurities and it is used when making so-called Swedish iron. Good charcoal iron is easily welded and will stand more bending without breaking than any other kind of iron. Wrought iron is almost entirely free from carbon and is very malleable and ductile, hence easily welded.

Steel. Steel is wrought iron with an appreciable percentage of carbon added, the amount depending upon the use to which it is to be put. It is made by simply stopping the air blast when making iron and leaving a small amount of carbon in the metal. This is usually at the point where the mixture still possesses the ductility and malleability of wrought iron together with the hardness and brittleness due to the carbon. This is why steel is both tough and hard and the amount of carbon determines the hardness. While wrought iron is slightly fibrous, steel is crystalline, but it may be improved by working at the proper temperature, and good steel is homogeneous throughout.

Soft Steel. Soft steel, or "mild" steel, as it is called commercially, contains very little carbon and is really on the dividing line between iron and steel. When it is made by forcing air through the molten iron to burn out the carbon, as previously described, it is called "Bessemer" steel, after the inventor of the process. The desired amount of carbon is afterwards supplied by adding an iron called "spiegeleisen" which contains both carbon and manganese, the latter enabling the iron to hold a larger amount of carbon and adding to its strength.

Open-Hearth Steel. Open-hearth steel is made by melting cast iron in an "open hearth" or broad shallow furnace and adding the proper proportions of scrap wrought iron or steel and iron ore. This is a very tough steel and is used for boiler plates and similar articles.

Per Cent of Carbon in Steel. In all of the processes the steel is cast into ingots and then rolled or forged into bars, sheets, or other shapes for commercial purposes. The amounts of carbon in iron and steel are approximately as follows

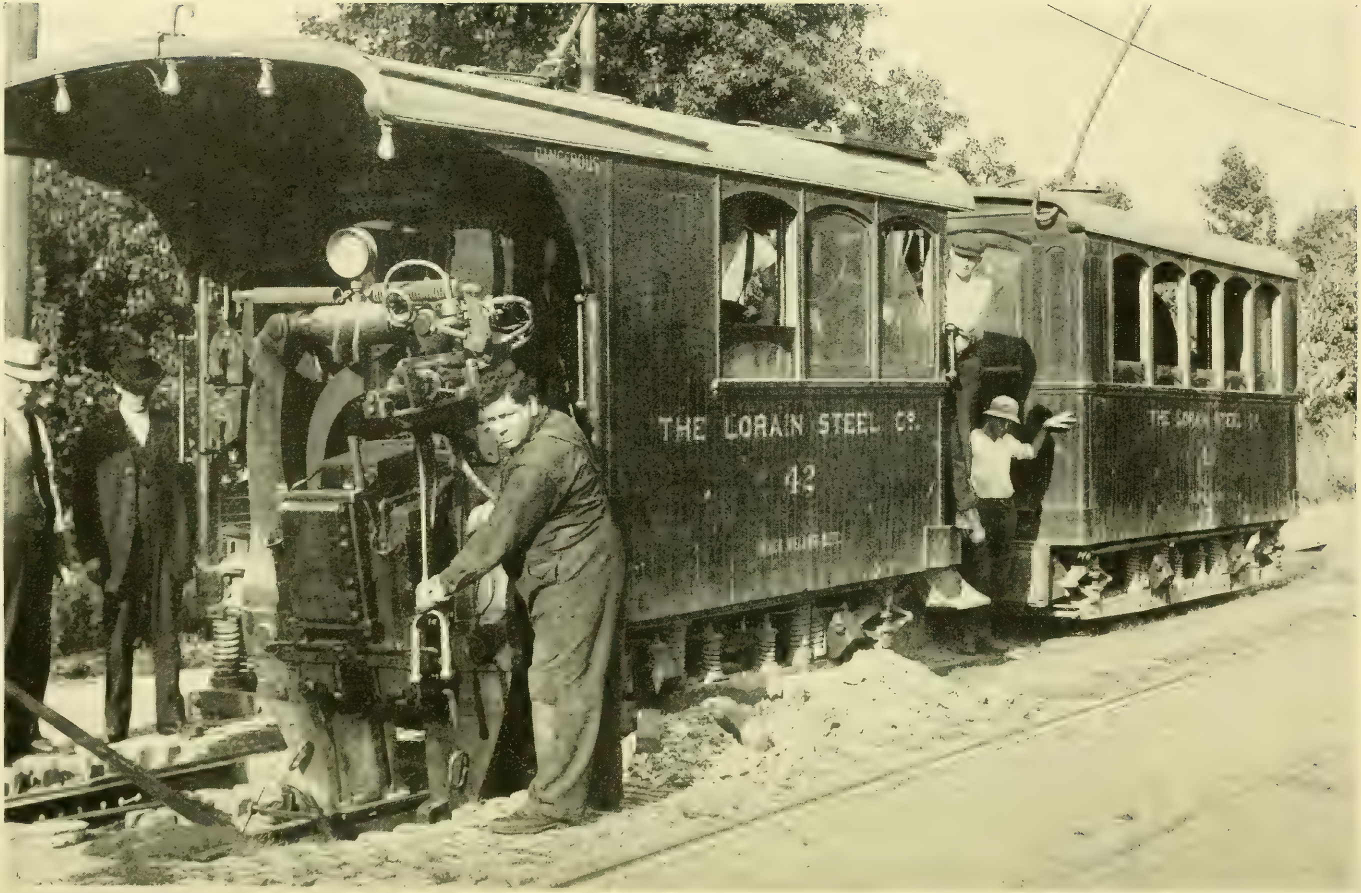
Cast Iron	3. % to 4.5%
Tool Steel	.5% to 2 %
Mild Steel	.1% to .5%
Wrought Iron	Less than .1%

Steel Castings. Steel castings are usually made of mild steel and contain small amounts of manganese, silicon, sulphur, and phosphorus in addition to the carbon. Manganese and silicon improve the steel but sulphur and phosphorus are not desirable. Aluminum is also added sometimes as a solidifier or deoxidizer before pouring the castings and it improves their quality. The amounts of these elements in steel castings usually vary as follows

Carbon	.18% to .75%
Manganese	.30% to .80%
Silicon	.27% to .33%
Sulphur	.032% to .056%
Phosphorus	.032% to .092%
Aluminum	Traces only after melting

Steel Alloys. The various elements used to alloy iron are technically known as "impurities", even though their addition is a distinct advantage. All of the alloys of iron and steel may be welded by any of the modern methods, although some of them cannot be welded by the blacksmith. *Silicon* causes brittleness and too much of it prevents welding, on account of the crystalline structure of the alloy, but the addition of manganese tends to overcome this and make it more weldable.

Manganese up to 1.5 per cent may be added to iron or steel without preventing welding, but more than that makes a brittle alloy. Manganese reduces both the sulphur and oxygen in the iron and adds greatly to its strength. *Nickel steel* may be welded and the addition of nickel up to 5 per cent is safe, if the amount of carbon is kept small. Nickel increases the tensile strength of steel without impairing the elasticity and also tends to prevent rusting of the iron alloy. *Chrome steel* may also be welded successfully.



TRACK WELDING MACHINE IN OPERATION

Copper. Copper is one of the elemental metals and is found as an ore and in a pure state. The ore must be smelted and the copper refined before it is ready for use in the arts like other metals. It is cast and sold in the form of ingots and should be at least 99.5 per cent pure and entirely free from sulphur. It is used largely in the form of sheets, bars, and tubes and occasionally it is cast in molds like iron and steel.

It is the principal element in brass, bronze, gun metal, and many other alloys, and is nearly as useful to man as iron. It can be welded readily by any method, although this is rarely done, for brazing and soldering have been the processes generally used for joining or repairing pieces of it. Great care must be exercised when casting copper to insure its being properly deoxidized and the same thing applies to welding it. Silicon, aluminum, and phosphorus are used for this purpose, although aluminum alone presents the disadvantage of oxidizing rapidly when exposed to the air.

Bronze. Tin and copper form a good alloy called "bronze", which is harder than either metal alone. The addition of tin increases the fluidity of copper but diminishes its ductility; the strength of copper is increased by adding up to 12 per cent of tin, and its crushing strength is increased by additions up to 18 per cent of tin. Beyond this latter point the bronze becomes hard and brittle. "Gun metal" is copper with from 8 per cent to 2 per cent of tin but the best alloy contains about 10 per cent of tin. Great care must be used when welding alloys containing tin because the latter melts at a comparatively low temperature and may easily be burned when welding.

Brass. Zinc and copper form the alloy known as "brass", and percentages of zinc as high as 40 per cent are sometimes used without serious effect on the malleability or ductility of the alloy but more zinc makes it very brittle. Tin is sometimes added to brass to increase its strength. Zinc is a good deoxidizing agent for copper but it vaporizes quite rapidly at high temperatures. This causes the zinc to pass out of the alloy, leaving the copper porous or spongy; this is why brass is so hard to weld satisfactorily. Lead is also used as an alloy for copper but not over 3 per cent can be used because it does not mix well.

Manganese Bronze. Manganese is alloyed with copper in various proportions for certain purposes. This alloy is known as "manganese bronze" and may be both forged and welded by proper methods, although welding is a rather hard process to perform satisfactorily with it. The ductility and strength are both very high and the alloy does not corrode easily, even in salt water. It weakens slightly when heated and shrinks more than gun metal; hence it requires special care during welding operations.

Phosphor Bronze. Phosphorus is also used with copper for making bearing metals and makes a strong alloy which resists corrosion. The percentage of phosphorus used when making "phosphor-bronze" castings ranges from 2 per cent down to but a few hundredths of one per cent; frequently the phosphorus causes hard spots because it does not always combine freely and thoroughly. This alloy is also hard to weld readily, although it may be done by proper methods.

Aluminum. Aluminum is the lightest of the commercial metals and is very valuable for forming alloys but it is rather hard to weld or solder because of the rapidity with which it oxidizes, especially at high temperatures. Castings of aluminum are being successfully welded now, however, by several methods; and sheets of aluminum are welded by the gas methods. The various alloys are also being welded; the heat conductivity is comparatively high and it acts like solder when melted; it melts at 655 degrees centigrade; it is easily burned; and a sort of scum forms on the surface, if welded with a high-oxygen flame.

Commercial welding is confined almost entirely to the metals here described, although gold, silver, platinum, and a few others are weldable and are used in some of the finer arts. The characteristics of iron, steel, and copper, however, are most important to remember in connection with commercial welding and manufacturing.

WELDING PROCESSES

Classification. While it is true that there are many variations of the principal processes of welding and joining metals, they may safely be placed in one of four general classes: smith or forge welding, electric welding, gas or hot-flame welding, and chemical welding. Included with these are such allied operations as soldering, brazing, and riveting for joining metals; so some reference will also be made to them, although the latter cannot be considered as welding in any sense of the term. Riveting is treated of here because it is one of the processes being superseded by the modern welding systems for some classes of manufacture, and the student should have some knowledge of the process and its relative value.

Smith Welding. Smith welding, or forging, is the general process of forming or joining metals by hammering or pressing the pieces into the desired shape and may be done either hot or cold, depending upon circumstances. When joining two or more pieces of metal, especially iron or steel, it is done hot and is one of the oldest of the useful arts. It is the most common of all of the welding processes but depends more upon the skill of the operator than any other process of welding; hence it is gradually being superseded by them. It is also rather expensive and slow and is not so suitable for large or heavy work as some of the other systems.

Electric Welding. Electric welding has been used as a laboratory process for a number of years but has recently been developed commercially to such an extent that it is rapidly coming to the front as the most important of all of the welding processes. Five different systems have been developed for using electrically generated heat for welding purposes, each of which has been named in honor of the inventor. These are the Thomson, Zerener, Benardos, Slavianoff, and LaGrange-Hoho systems, of which the Thomson has two forms, viz., "butt welding" and "spot welding," the names indicating the kinds of joint formed.

The *Thomson system* requires the use of alternating current whereas the other systems use direct current for welding. The Thomson system and its latter day modifications consist in bringing together the two pieces to be welded, in a special machine, passing an alternating current through the point of contact until the parts are heated sufficiently to be soft and then squeezing them together until they unite. The heating is due to the resistance of the joint to the passing of the current before the parts are soft enough to weld.

The *LaGrange-Hoho system* is also based on resistance and consists in placing the pieces of metal in a bath of electrolyte, causing the current to flow to them from a positive electrode and heating them until soft enough to weld. The actual weld is made by hammering, the same as smith welding; so this is not at present a very important process commercially.

The three other processes use the electric arc as the source of heat, and do their work by filling in additional material to join the pieces. The *Zerener system* is based upon using two pieces of carbon in a suitable holder, causing the arc or flame to be deflected toward the work by means of a magnetic field and using the arc to melt the filling material. The *Benardos system* consists in using a piece of carbon or graphite as one electrode for the arc, drawing the arc between the carbon and the work (which is the other electrode) and using the heat of the arc to melt the filling material required for joining the pieces.

The *Slavianoff system* also consists in drawing an arc between the work and an electrode, but a piece of the filling material is used as one of the electrodes and melts directly into place on the job. This is the most important of the electric welding processes, although it is the most recently developed to a commercially practical point. It is applicable to practically every class of welding and for nearly all metals, and is the simplest of all welding processes. It will probably be in universal use within a very few years.

Gas Welding. Gas welding, or hot-flame welding, is at present next in importance to smith welding and is applicable to many kinds of work which cannot be done by forging. The three most important processes commercially are known as the *Oxy-acetylene, Oxy-hydrogen,* and *Blau-gas processes.* All of these processes consist in using oxygen and another gas to give a flame of sufficiently high temperature and heating capacity to melt the material to be welded, the gas used with the oxygen being indicated by the name of the process. In all cases the oxygen and other gas are mixed in a suitable burner and the flame directed on the work in such a way as to cause the metals to flow together and, when no extra material is added to form the weld, it is said to be "autogenous" or self-forming. Electric-arc welding is also autogenous to the same extent, although the term is not strictly correct. The details of these systems will be described later.

Chemical Welding. Chemical welding is exemplified today almost exclusively by the process known as "thermit welding" and consists in igniting a mixture of oxide of iron and aluminum so as to set up a chemical reaction which evolves an intense heat. This is done by placing the mixture in a suitable mold and igniting, causing the aluminum to reduce the iron from its oxide, thus evolving the heat required and forming what is called "thermit-steel". The molten steel is allowed to run out of the mold and into and around the part to be welded, thus forming a "cast-weld" of considerable strength. A suitable mold must also be formed about the part worked upon in order to retain the metal until cooled; so this process is comparatively slow and expensive. Several other chemical processes have been developed but as they are not of very great importance commercially at this time, they will not be described here.

Brazing and Soldering. Brazing and soldering are processes which approach welding so closely in some of their applications that they are worthy of serious consideration as a part of that subject. *Brazing* consists in joining metal by fusing a filling material called "spelter" into the joint by heating, first preparing the surfaces of the joint with a suitable flux. When brass is brazed, it really becomes a welding process because brass is the principal constituent of spelter. The heat is produced by a gas flame and the work is done at a comparatively high temperature.

Soldering, or "metallic gluing", as it has been called, is done by melting a soft alloy into the space between the parts to be joined. It can be done with a gas flame or a heated soldering copper and at comparatively low temperatures. Soldering is a comparatively old process, is cheap, easily learned, and in wide use, but it should not be used for any joint requiring much strength. It is not suitable for joints in iron or steel or in several of the alloys.

Riveting. Riveting consists in joining plates, sheets, or other shapes of metals by means of small pieces of metal which pass through the parts and are headed over on both sides. This process is also old and will be described in detail later in order to bring out the comparison between this and the newer methods of joining materials.

Miscellaneous Processes. Several other processes of joining metals are being advocated by their inventors, among which may be mentioned the "Ferrofix brazing process" and the "Laffitte welding plate", although neither of them is in very extended use at present. *Ferrofix brazing* consists in cementing together two pieces of iron by means of a thin film of brass in such a way that the brass alloys with the iron and forms a joint that is stronger than the iron.

The necessary heat is supplied by a gas flame of suitable temperature. *Laffitte welding plate* consists of a special chemical preparation molded over a sheet of wire gauze and it is used by placing the plate between the surfaces to be welded. The parts are heated to a cherry red, the plate inserted, and the pressure applied while the reaction takes place. The preparation of the plate is such that it supplies the flux, the reagent, and the filling material and makes a joint of relatively high strength. Both of these processes have been introduced into the United States but recently and their relative values have still to be determined; they will be described in detail later.

SMITH WELDING OR FORGING

Smith welding is the process of joining metals by laying the pieces together and hammering at the place of contact until they become one piece. Most metals must be heated nearly to the temperature at which they begin to flow, before they can be welded. For iron and steel this is at the white heat; so let us first consider the action of the fire and the equipment required before taking up the study of the process in detail.

Producing the Proper Temperature. The combustion of fuel, either coal, coke, oil, or charcoal, causes the oxygen of the air to combine with the carbon of the fuel, and this chemical combination is what produces the heat. The *amount* of heat produced depends upon the amount of carbon and oxygen combined during combustion; whereas, the *temperature* attained depends entirely upon the rapidity with which the combination takes place. This is one of the most important facts to be learned in connection with welding, because the principle involved applies to all of the other systems of welding as well as to smith welding.

Forced Draft. Ordinarily, combustion would not be rapid enough to generate the amount of heat required for welding; so a draft is created through the fire in order to supply enough oxygen to the fuel and increase the rate of combustion. Too much air will chill the fire or blow it out, and an excess of oxygen will cause some of it to combine with the iron and form a scale of oxide of iron. This is called an "oxidizing fire"; whereas, if the oxygen is all consumed in the fire and there is an excess of carbon, it is then called a "reducing fire".

Fuels. Coal, coke, charcoal, oil, and gas are all used as fuels for forges, but charcoal is the best because it is almost free from impurities. Coal and coke are good unless they contain sulphur and phosphorus. Sulphur makes iron "hot-short", or brittle when hot, and phosphorus makes it "cold-short", or brittle when cold.

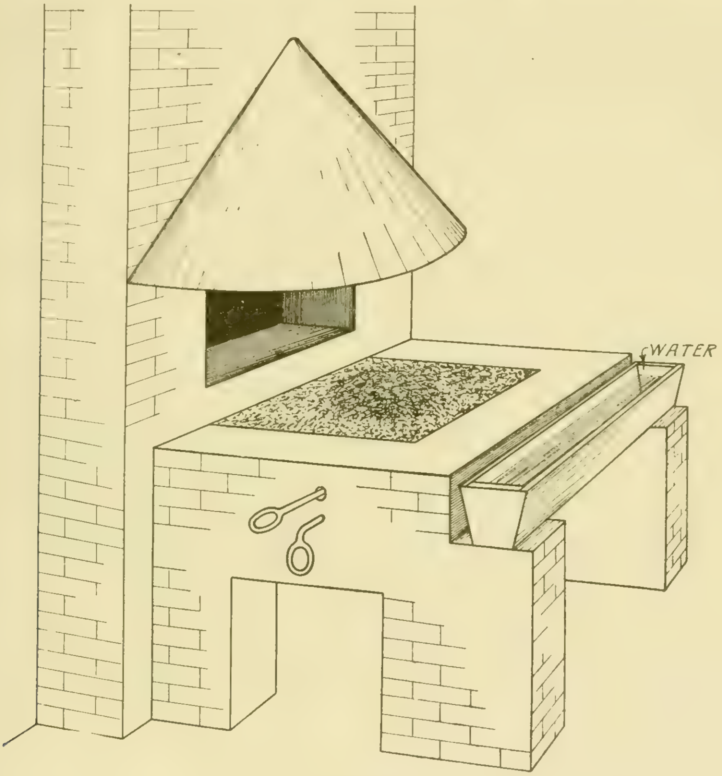


Fig. 1. Brick Blacksmithing Forge

Copper, lead, tin, and other non-ferrous metals should be kept out of the forge as they will spoil iron for welding.

Forges. Forges are of various kinds, usually of brick or iron, Figs. 1 and 2, and consist primarily of a bowl with an air inlet or "tuyere" in the center of the bottom, a hood overhead to carry smoke and fumes to the chimney, a blower or bellows to supply air, an ash pit, and a trough or other vessel for water. Usually a blast of air at a pressure of from 4 to 6 ounces per square inch should be maintained. A type of portable forge is shown in Fig. 3.

Forging Tools. *Anvil.* An anvil is required to provide a surface upon which to lay the pieces, when hammering to make the weld. It may be of cast steel or of wrought iron with a steel face, and usually weighs from 150 to 200 pounds. The anvil should be placed on a block of hard wood, Fig. 4, and securely fastened to it, and the height should be such that a man's knuckles will just reach to the top of it when he stands alongside.

Hammers. Hammers and sledges of various sizes and styles are required. Hand hammers, Figs. 5, 6, 7, and 8 weigh from 1 to 2½ pounds and have handles from 14 to 16 inches long. Hand sledges, Fig. 9, weigh from 5 to 8 pounds and have handles from 24 to 30 inches in length. They are handled by a helper. Swing sledges, Fig. 10, weigh from 8 to 20 pounds and have 36-inch handles. They are used for heavy work only and the helper strikes a blow with a free full-arm swing.

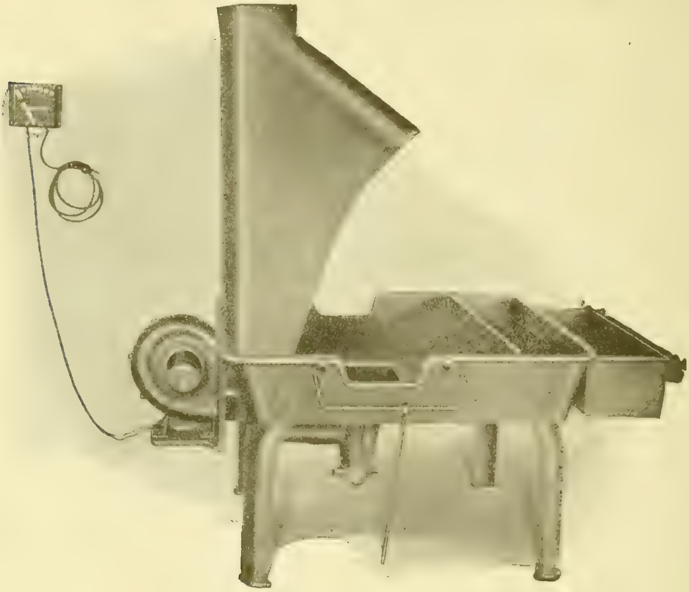


Fig. 2. Modern Motor-Driven Forge
Courtesy of Canedy-Otto Company

Ball-peen, or chipping, hammers, Fig. 7, have a round top or ball-shaped peen on the head. The striking face is flat, but the peen head is used for riveting or for stretching metal by hammering. Cross-peen hammers, Fig. 8, have a long ridge running across the

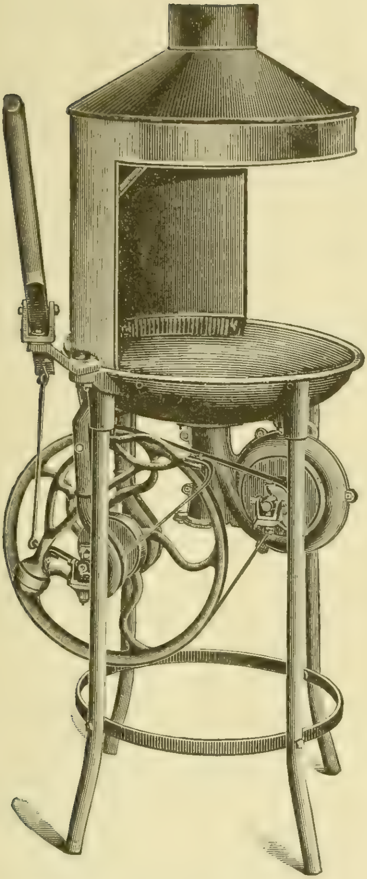


Fig. 3. Portable Hand Forge
Courtesy of Canedy-Otto Company

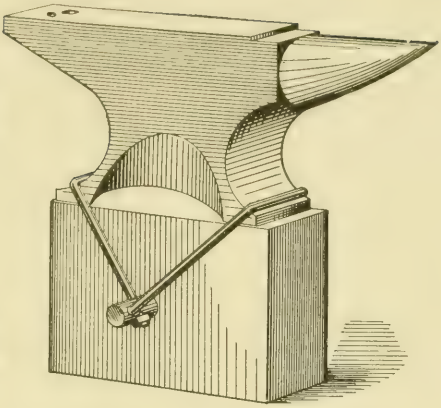


Fig. 4. Anvil Fastened to Block

top of the head and are used when stretching metal lengthwise and for riveting. Straight-peen hammers, Fig. 5, have a ridge running lengthwise of the head and are used when the metal is to be spread sidewise. Hammers should be selected to suit the work to be done and the strength of the user, and they should be of the best quality.

In addition to the foregoing hammers for general use, there are

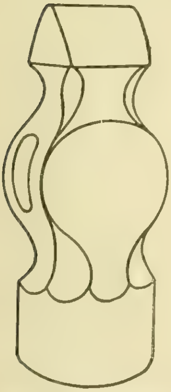


Fig. 5. Straight-Peen Hammer

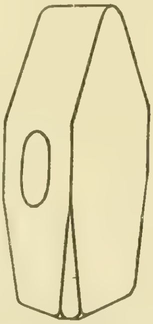


Fig. 6. Long-Peen Hammer

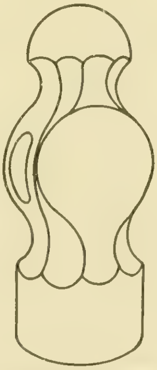


Fig. 7. Ball-Peen Hammer

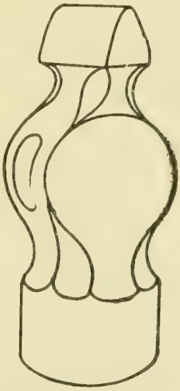


Fig. 8. Cross-Peen Hammer

various kinds for special purposes. These include "set" hammers of various shapes, for forming the iron. Square set hammers, Fig. 11, are for producing flat surfaces; flatters, Fig. 12, are for similar use but cover a wider area; fullers, Fig. 13, are for spreading out the iron, hollowing out work, and forming shoulders; swages, Fig. 14, are for rounding pieces of iron and are of numerous sizes; punches, Figs. 15 and 16, are for making holes and are made square and round; and cutters, Figs. 17 and 18, are hammers with chisel-like edges on the top of the head for cutting bars, etc.

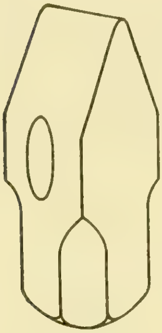


Fig. 9. Hand Sledge

Anvil Tools. Anvil tools with stems to fit the square "hardie" hole in the anvil are made in shapes to match the set hammers previously described. They include fullers, swages, hardies, heading tools, etc., Figs. 19 and 20.

Tongs. Tongs are of many kinds and special ones are easily made when peculiar pieces are to be worked. Flat tongs, Fig. 21, are used for flat iron bars, strips, or plates. Pick-up tongs, Fig. 22, have curved springy jaws and are used for handling small pieces. Bolt tongs, Fig. 23, have a sort of pocket in the head or jaws for holding bolts while forming them. Gad tongs, Fig. 24, are shaped somewhat like bolt tongs except that the nose of the jaws is flattened somewhat like flat tongs. They are used for holding

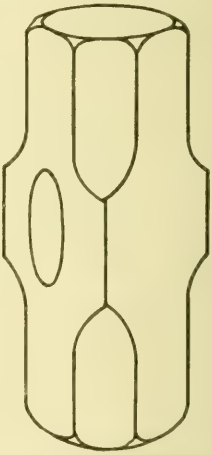


Fig. 10. Swing Sledge

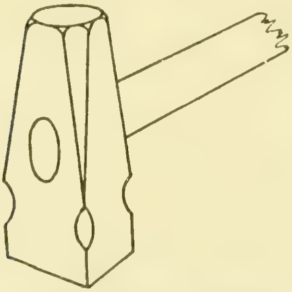


Fig. 11. Square Set Hammer

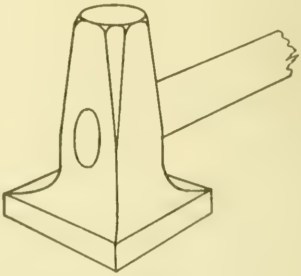


Fig. 12. Flatter

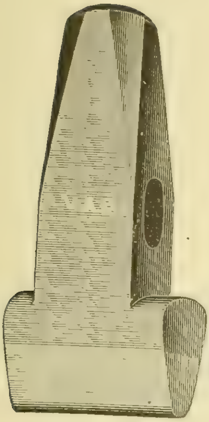


Fig. 13. Fuller

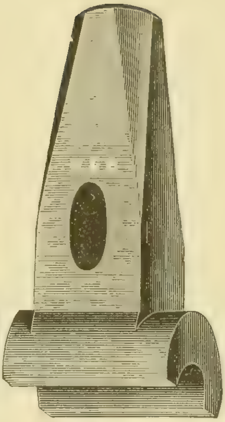
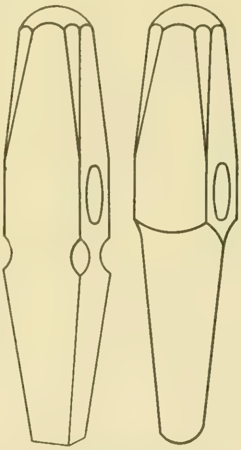


Fig. 14. Swage

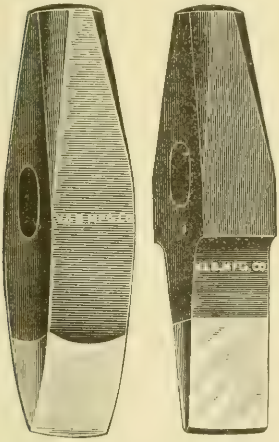
Courtesy of Vaughan and Bushnell Manufacturing Company

flat pieces which are thick at one end or side. Tongs soon become spoiled by the constant dipping in water and they bend out of shape easily while hot. They should not be left in the fire unless necessary and should be kept in a rack when not in use.

Miscellaneous Equipment. In addition to the foregoing essential equipment, smith shops frequently contain many other tools such as dies, swage blocks, vises, surface plates, gages, taps, dies, calipers, Figs. 25 and 26, etc. For handling the fire there should be provided a poker, fire hook, shovel, sprinkler, and ladle, Figs. 27 and 28. A monkey wrench, chisel, and a pair of "C" clamps are also useful, and a tapered mandrel will be needed if rings are to be welded. A large portion of the equipment here mentioned will also be required for welding by any other method and a well-equipped shop is generally a good investment. On the other hand, it is usually better to start with the smallest equipment which will do the general run of the work and then buy special tools and equipment which experience shows to be necessary.



Figs. 15 and 16. Square and Round Punches



Figs. 17 and 18. Cold and Hot Cutters

Courtesy of Vaughan and Bushnell Manufacturing Company

General Features of Smith Welding. The process of smith welding, or forging, is comparatively easy to learn, but skill and the ability to use the process successfully will only come after long practice. The first operation to learn is to heat the iron properly; this is done by placing it in the fire until it reaches a bright red, almost white, color. Large pieces will take longer to heat, and will remain hot longer, than small ones and the surface will tend to oxidize and flake off upon exposure to the air while hot. For ordinary forging operations this is no disadvantage beyond reducing the size of the piece slightly but, when welding two pieces together, this oxide

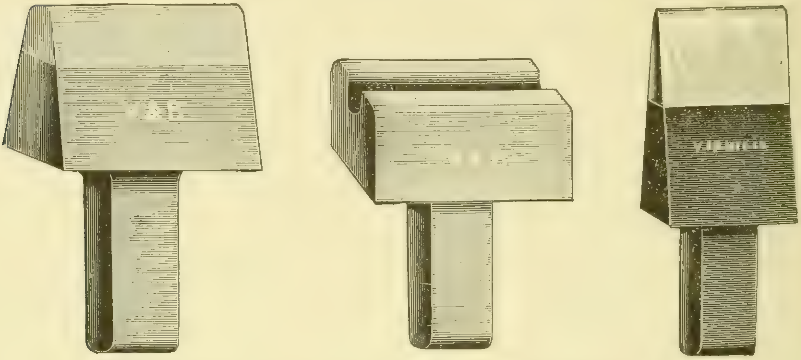


Fig. 19. Bottom Fuller and Swage and Hot Hardie
Courtesy of Vaughan and Bushnell Manufacturing Company

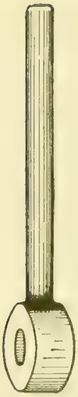


Fig. 20. Heading Tool

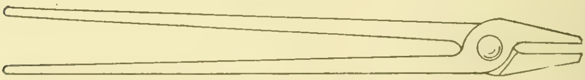


Fig. 21. Flat Tongs

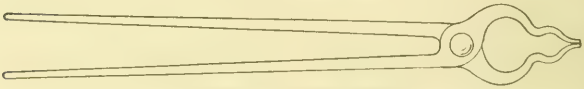


Fig. 22. Pick-Up Tongs

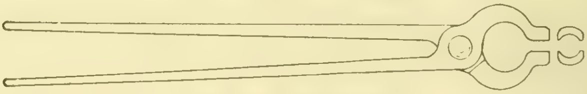


Fig. 23. Bolt Tongs

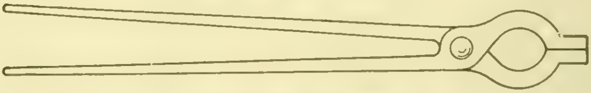


Fig. 24. Gad Tongs

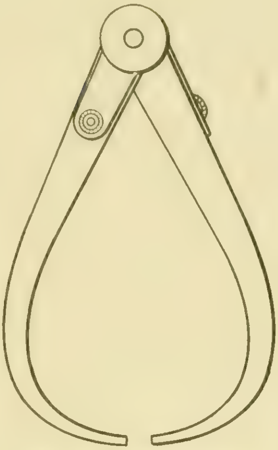


Fig. 25. Outside Calipers

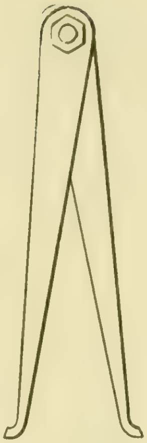


Fig. 26. Inside Calipers

must be kept off by the use of a good flux or it will destroy the value of the weld by preventing cohesion of the particles forming the pieces. The most common flux for iron is clean sharp sand because it will fuse and stick to the surface and keep out the air; but work can be done without a flux, if it is done quickly. For steel, it is better to use potter's clay, wet with strong brine and then dried and powdered. Borax is sometimes used but it is not good for the metal.

Simpler Operations Performed First. The simpler operations of forging should be learned first and then the welding tried afterwards. "Drawing" is the operation of stretching the iron in one or two directions and it consists in hammering the hot piece on all sides for lengthening or on one side for flattening or spreading. If the piece tends to curl, it can be hammered on both sides to keep it

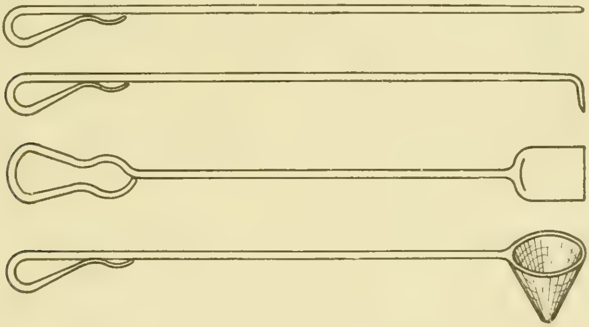


Fig. 27. Types of Fire Handling Tools

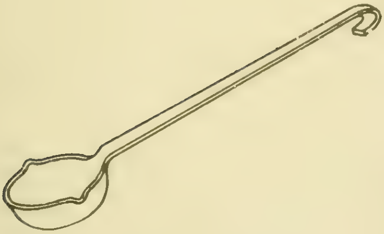


Fig. 28. Ladle

flat. Square pieces should be turned over and over and hammered on all sides in drawing, and round ones should be hammered on all sides. "Upsetting" is the operation of increasing the diameter or thickness of a piece by heating and then hammering it on the ends until it becomes shorter through the flowing of the metal to the heated portion. The bar usually tends to bend under this operation; so it should be straightened at once by hammering on the high side. Considerable heat is required for upsetting and the fibers tend to separate or split apart, when the piece is hammered lengthwise of its grain; so it is well to finish the upsetting by heating again and hammering all around to weld the fibers again. Bolt heads are formed by upsetting the bar on the end and hammering square, or hexagonal, as required.

When forming corners which must be square, the pieces must first be upset to get enough stock and, when making connecting rod straps, crank shafts, rocker arms, hook eyes, eyebolts, axe heads, armature shafts, and other articles of variable thicknesses, it is customary to upset them from straight bars before beginning to shape them. After the student has practiced the more elementary operations described and becomes familiar with his tools and his metal, he can then try welding.

Kinds of Welds. There are several kinds of joints made by smith welding, each of them being known by a name which indicates the manner in which the pieces are joined. These are the "scarf weld", "butt weld", "lap weld", and "cleft weld", and the proper one to use will depend upon the shape of the piece and the strains it will meet in service.

Scarf Weld. The scarf weld, Fig. 29, is made by "scarfing", or thinning the pieces at the end, in order to give them a bevel; the iron should be upset a little to give enough extra stock to allow for the drawing down when hammering. The pieces should be rounded slightly on the surfaces which come together in order to allow the scale and slag to squeeze out and then they should be hammered while at a white heat. When they are thoroughly joined, the piece should be shaped all around by turning while hammering.

Butt Weld. A butt weld consists in hammering two pieces end to end until they unite, the pieces being rounded slightly on the ends, Fig. 30, to allow the scale to come out. This operation will tend to

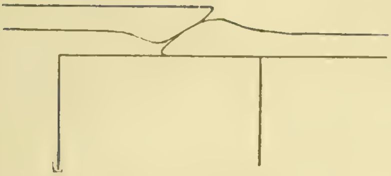


Fig. 29. Scarf Weld

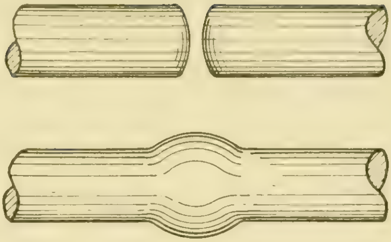


Fig. 30. Butt Weld

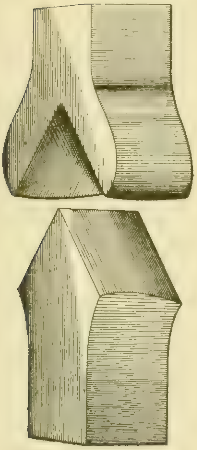


Fig. 32. Cleft Weld

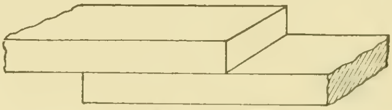


Fig. 31. Lap Weld

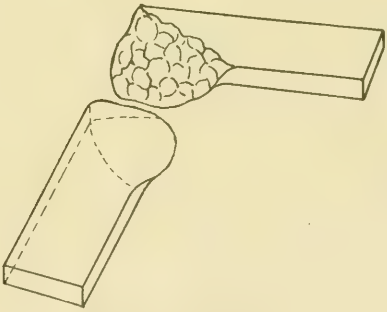


Fig. 33. Corner Weld

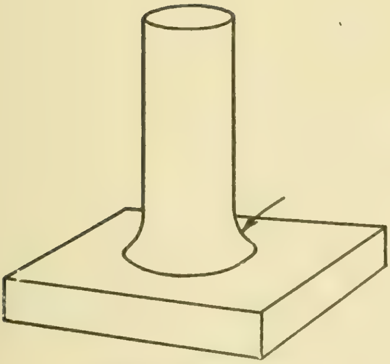


Fig. 34. Jump Weld

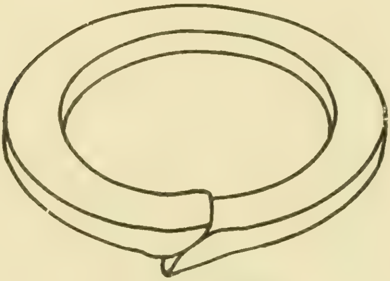


Fig. 35. Ring Weld

upset the pieces and they should be drawn down to size again after welding. This sort of a joint is not so strong as a good scarfed joint.

Lap Weld. A lap weld, Fig. 31, is made by simply laying one piece on top of the other and hammering until they unite. Work should start at the center and proceed toward the outside in order to force out the slag; otherwise the metal will not unite. It is not necessary to round up the parts for this joint, but a better job is insured if it is done.

Cleft Weld. A cleft weld, Fig. 32, makes the strongest joint and consists in splitting one piece at the end, tapering the other piece, and slipping it into the fork of the first piece; then, by hammering the sides of the cleft together, the pieces are made to unite. The pieces should be first hammered on the ends in order to drive them tight together in the cleft, and it is good to round the sides of both pieces on the welding surfaces to allow slag to flow out.

Applications of Smith Welding. The applications of smith welding are numerous, but a few of them will serve to give an idea of the possibilities. Scarf welds are used to form the corners of frame work made of flat bars, Fig. 33, and one piece is beveled on the end and the other on the side and the joint is made as previously described. Jump welds, Fig. 34, are also made by scarfing the pieces in the same way and welding; and rings, Fig. 35, are made by scarfing the ends of the strip and welding. To determine the length of a piece for making a ring, add the thickness of the stock to the inside diameter of the ring and multiply by $3\frac{1}{7}$. For straight pieces to be welded, add the thickness, or diameter, to the length to allow for the joint.

Butt welds are used, when joining heavy pieces—especially pieces of irregular shape that are to be upset first—and for lengthening pieces of large cross section, such as shafting. Lap welds are used for comparatively thin sections like steel tires, hoops, and plates, and sometimes for making tanks and large piping. Tubes are sometimes lengthened by swaging one part large enough to slip over the other and then lap-welding them by hammering with a mandrel inside to prevent distortion, and to give something to act as the anvil to hammer against. Cleft welds are used when welding steel to iron, as, for instance, putting hard tips on picks, attaching tool steel drills to soft shanks, etc., and for work requiring great strength of joint, such as tie-rods for bridges. Borax should not be used as a flux for this purpose, unless it has first been calcined or melted in a ladle, cooled, and powdered in order to remove all moisture from it. When making a weld between iron and steel, it is best to heat them both at once; dip the iron in sand and the steel in borax; reheat the iron white and the steel cherry red; and then weld with a heavy hammer. After they are joined, they should be reheated and then finish with a lighter hammer. Steel facing is another welding operation and consists in welding a piece of steel flatwise against the iron to give it a hard surface; it is used in making some kinds of tools.

SOLDERING AND BRAZING

Both the soldering and brazing processes are similar to welding in so far as they are methods of uniting metals, but they are different in that the filling or joining material is usually of different composition from the pieces joined. The work of brazing brass and soldering lead resembles the welding process without the hammering but it is not welding in the proper sense of the term; it is, rather, a sort of "metallic gluing" process.

Soldering

Soldering is the process of joining pieces of metal by filling the space between them with material known as "solder", and doing it in such a way that the solder will adhere to both of them and hold them together. The first requirement of a good solder is that it will "wet" the surfaces, or amalgamate with the pieces to be joined. Alloys of lead and tin, with the addition at times of other metals, are the usual solders, although special solders are made without either of them. Soldered joints are not so strong as welded or brazed joints because of the material used but they are frequently used because they are easily and cheaply made.

The process requires less heat than welding or brazing and the joints may be cooled rapidly. An ordinary gas flame with a foot pump for the blast, or even a candle and a blowpipe, may be used for soldering. If the piece worked upon is so large that it rapidly conducts away the heat, a gasoline or kerosene torch is used to preheat the piece and prevent chilling the solder. The blowpipe is used for small work like jewelry and the only point to watch is to be sure the flame is hot enough to burn all of its carbon. The blue center of a flame is highly oxidizing whereas the yellow outside portion causes a reducing action.

Fluxes. Fluxes are essential to successful soldering and there are several kinds on the market, although most operators soon learn to make their own. The fluxing materials generally used are salammoniac zinc-chloride solution, rosin in alcohol, borax, and tallow. Flux is used to dissolve grease and to remove any oxide present after cleaning. It combines chemically with the oxide and leaves a clean surface of metal which the solder will wet. Sometimes the flux is combined with the solder when making up the sticks, and this is known as "self-fluxing" solder.

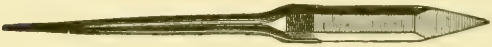


Fig. 36. Soldering Copper
Courtesy of Central Electric Company

Tools. The tools required for soldering are very simple and few in number. The source of heat for the operation is usually a soldering "copper" or "bit," Fig. 36, which has in turn been heated in a gas or charcoal stove, Figs. 37, 38, and 39. It is made with a comparatively large head, small shaft, and wooden handle and has a pointed tip on the head for working. The tip should be "tinned" before using, and this is done by first cleaning and sandpapering, fluxing with zinc chloride, and heating. While hot it is rubbed well with a stick of tin which adheres to the surface, and it will remain tinned for a long time unless heated to a red heat. A type of grooved soldering copper is shown in Fig. 40, and an electric soldering tool is shown in Fig. 41.

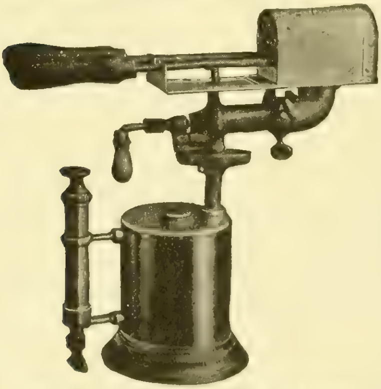


Fig. 37. Soldering Iron Heating Stove
Courtesy of Central Electric Company

Solders. Most solders melt at about 200 degrees centigrade (392° F.), the softer solders melting at about 180 degrees centigrade (356° F.) and harder solders at about 330 degrees centigrade (626° F.).

There are so many special solders on the market that no closer figures can be given, but these will be a safe guide for most of the ordinary kinds of work. Ordinary solder is half tin and half lead. Hard solder is two parts lead and one part tin. Antimony is sometimes added to harden and stiffen solder, and arsenic is added to make it flow more freely. Bismuth makes the solder brittle and cadmium makes it soft. When bismuth and cadmium are both added they reduce the melting point, and "Wood's metal", which contains two

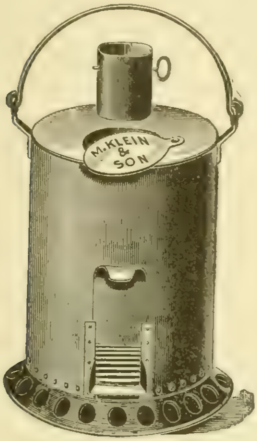


Fig. 38. Charcoal Stove
Courtesy of M. Klein and Son

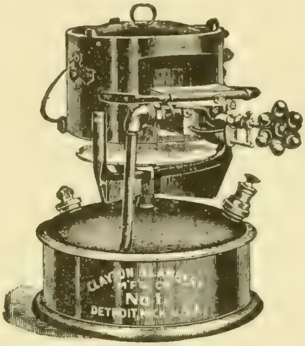


Fig. 39. Gasoline Furnace
Courtesy of Central Electric Company

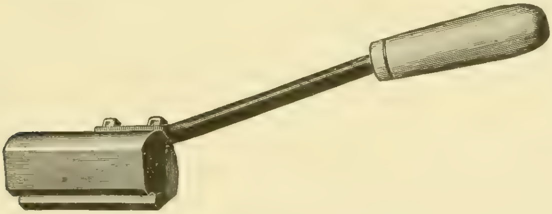


Fig. 40. Grooved Soldering Copper
Courtesy of Central Electric Company

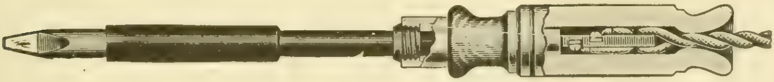


Fig. 41. Electric Soldering Tool
Courtesy of Central Electric Company

parts of tin, two of lead, two of cadmium, and eight of bismuth, melts at 70 degrees centigrade (158° F.). Copper strengthens solder but raises the melting point very rapidly.

Soldering Process. The process of soldering consists in first scraping the surfaces clean; heating the pieces to the soldering temperature by any suitable means; fluxing the surfaces to be joined; applying the solder with the solder bit; and finishing the joint by smoothing off. Rust and grease must be scraped or washed off with some alkaline solution. With liquid fluxes it is best to apply them after heating the surfaces to be joined, in order to eat away the film of oxide and keep the surface clean but, with borax or rosin solutions, it is best to apply them cold. After the surfaces are properly cleaned, heated, and fluxed, the solder is melted on with a flame or by rubbing with a hot bit and then the joint is smoothed up.

The most important points to watch are the temperature and the flux. Too much heat causes oxidation, makes the solder run too freely, and burns the tinning off the soldering tips. Poor fluxing prevents the solder from amalgamating with the pieces and, hence, they will not join. Platinum, silver, gold, tinned sheet iron, and most other metals may be soldered but it has thus far been practically impossible to solder aluminum commercially. A number of processes have been devised for soldering aluminum but none of them are in very general use and most of them have been failures.

Brazing

Brazing is a process similar to soldering, the main difference being in the use of a harder filling material and one requiring a higher melting temperature. Gold, silver, copper, brass, and iron may be brazed and the process consists broadly in melting a filling material called "spelter" into the joint to be made. The spelter used for brazing varies with the nature of the work, the hard alloys consisting of copper and zinc, and the soft ones consisting of tin and copper, or tin and antimony. Hard spelter gives a stronger joint than soft spelter, of course, but in all cases the spelter must amalgamate with the metal joined in order to make a good joint.

Flux. The flux for brazing is made of borax or boracic acid, the latter being cheaper. Borax will swell up under the flame, blister, and run off unless the water of crystallization has been burned out, whereas good borax will melt and run over the surface and clean it nicely. The surfaces should be cleaned carefully before brazing, the same as when soldering. Salammoniac, zinc chloride, salt, and various acids have been tried as brazing fluxes but none are so good as borax.

Equipment. The equipment required for brazing consists principally in having suitable means for heating the pieces to the proper temperature and a supply of the proper spelter. Beyond this there are many good things which assist in making brazing easier, such as special fixtures for holding the pieces while working, torches or furnaces of various sizes, and similar things which will suggest themselves to the worker from time to time. As stated, the things which are necessary are but few in number.

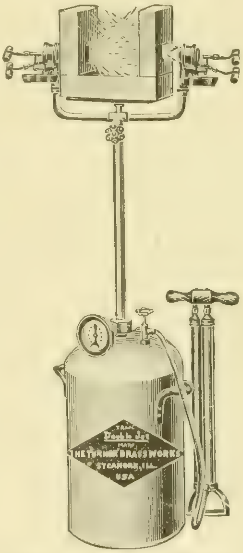


Fig. 42. Double-Jet Brazer
Courtesy of Turner Brass Works

A torch is used when brazing small and moderate-sized pieces and a forge or furnace such as shown in Fig. 42, for heating large pieces. Gasoline or kerosene give more heat than gas, but a blacksmith's forge provides the best means for heating and cooling. The pieces to be brazed should be preheated, brazed, and cooled slowly, and care must be taken to see that any sulphur in the coal or any soot from the fire is kept away from the pieces to be welded. The parts should not touch the fuel. A reducing or nonoxidizing flame is required and the brazing is done at a high temperature. Iron and steel require almost a white heat and a Bunsen flame with a blue cone is generally used.

Process of Brazing. The process of brazing varies according to the work to be done and is a somewhat more expensive and complex process than soldering. The surfaces to be brazed must be cleaned, of course, by scraping and washing, and then brushing with a wire brush. The borax or other flux is then applied and the pieces placed together ready for brazing. The tighter the parts are clamped, the stronger will be the joint. If no regular furnace is available, a rough one should be built of bricks, Fig. 43, so as to enclose the articles on all sides but one, in order to retain the heat.

There is considerable variation in the practice of brazing, for the details of the operation depend upon the nature of the work to be done, the size and the shape of the pieces, the material, etc. For the production of pieces in quantities, especially articles made of sheet metal, the spelter is melted in a ladle or pot and the pieces are dipped therein. In this operation the flux is floated on top of the spelter and the pieces are cleaned before dipping. The flux then does its work as the articles are dipped into the spelter.

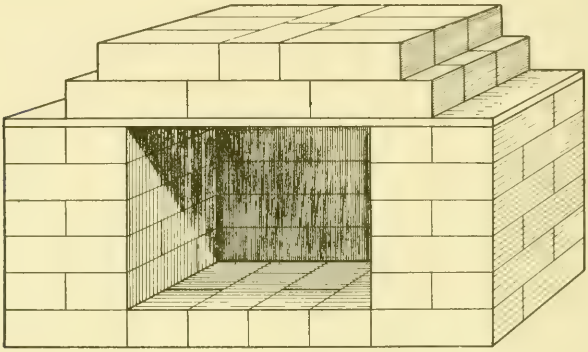


Fig. 43. Temporary Brick Furnace for Brazing

For castings and other articles which require brazing, but which cannot be dipped because of the nature or location of the joint, it is customary to prepare the joint as previously described; place the pieces together in proper position; build a temporary furnace around the piece, or place it in a suitable furnace; and then heat it by playing a flame on it. Gas torches with air blast, Fig. 44, make good heaters and the temperature may be regulated to suit the size

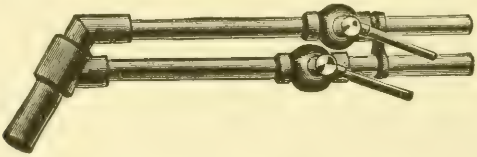


Fig. 44. Hand Gas Torch for Brazing
Courtesy of Turner Brass Works

of the piece. When the article is properly heated and fluxed, the spelter will flow into the space between the parts, wet both surfaces fully, and make a tight joint.

Care should be taken to see that the article does not cool too quickly, especially iron castings, or unequal shrinkage will cause cracking. Heating should also be gradual to prevent unequal expansion for the same reason and burning must be avoided. Sometimes the pieces may be covered with graphite paint, except where the brazing is to be done, thus preventing the flame affecting those parts. This is especially important when brazing brass as it should prevent the zinc from volatilizing and passing out of the alloy, thus leaving it spongy. The brazing of gold and silver requires special alloys; this is usually put in the hands of a jeweler and, as it is generally a small job, it is usually done with a blowpipe.

Use of Brazed Joints. Brazed joints are often stronger than the original metal but are not so good as welded joints, although they are cheaper and easier to make. Cast-iron pieces will not break at the joint, when properly brazed, and such joints are about 15 per cent stronger than the casting. One of the greatest objections lies in the possibility of leaving flux or rust in a brazed joint and weakening it. There is also danger of electrolytic action between the spelter and the material brazed and brazed joints do not always stand up well under repeated shocks. On the other hand, on articles of steel there are probably more joints made by brazing than by any other process (except riveting), thus proving it to be a generally reliable commercial process.

RIVETING

Riveting is not a welding process but it deserves a place in any treatise on the art of joining metals because it is in such general use for that purpose. While it is true that riveting is rapidly being superseded in many cases by various welding processes, it will never be abandoned entirely and is therefore worthy of consideration here.

Details of Process. The process of riveting consists in joining pieces of metal by means of rivets, which are short pieces of soft bars or rods with a head on one end. They are usually made of the same material as the pieces to be joined, such as steel, iron, copper, brass, aluminum, etc., and are used hot or cold as may be required. Steel and iron rivets for joining plates or other pieces of the same materials are usually red-hot when used; so they are easier to head over and will draw the pieces tightly together as they shrink while cooling. Rivets of softer materials are used cold.

Shapes of Rivet Heads. The more common forms of rivet heads are shown in Fig. 45, wherein *A* shows a plain round head on both sides of the plates; *B* shows a round head on both ends but with the plates slightly countersunk to form a shoulder under the head for added strength; *C* shows a plain rivet with a pointed or steeple head above and a rose, or cone, head below; *D* shows a countersunk head above and a round head below; *E* is similar to *D* with the lower plate countersunk to give a shoulder under the head, and *F* has countersunk heads both above and below. Round heads are most commonly used; steeple and cone heads are used for boilers; and countersunk heads are used only when necessary for finish or to avoid some other attachment.

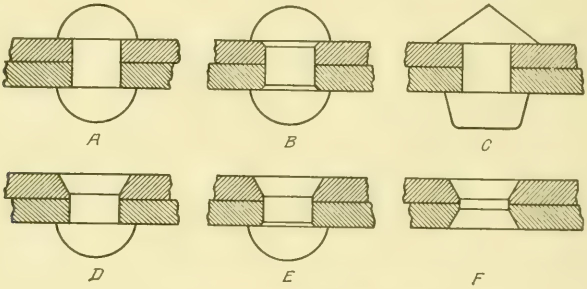


Fig. 45. Types of Rivet Heads

Tank and Boiler Work. When making tanks, pipes, boilers, or other articles of steel plates, the first operation is to shear the plates to the desired size and then trim the edges. Rivet holes are then punched or drilled near the edges of the plates, these being of the proper size and quantity for the strength demanded. If the article to be made is cylindrical in form—such as a boiler—the plates must be bent to the proper shape by being passed through rolls after the rivet holes are made. A few bolts should be put into some of the holes, after the plates have been placed in proper position for riveting, in order to hold the plates in place until the rivets have been driven and set. These can then be removed and rivets substituted for them. Rivets always used to be headed over by hand but machine riveting has been adopted now for nearly all work done in shops and a large part of that done in the field; it is much to be preferred on account of its uniformity.

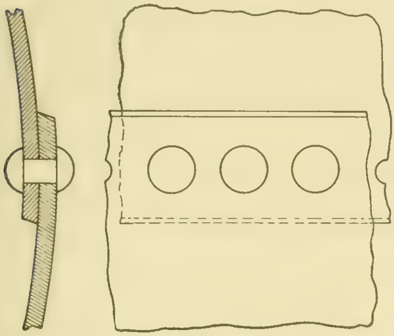


Fig. 46. Single-Riveted Lap Joint

Types of Joints. The joints used in riveting plates are either of the lap or of the butt type; a lap joint is one where the plates are laid on top of each other, and a butt joint is one where the plates come together edge to edge with another plate covering the joint. The added plate is known variously as a "welt strip", "cover plate", or "butt strap"; two of them are used for extra heavy work. Where the plates lap over and a single row of rivets is used, the joint is known as a "single-riveted lap joint", Fig. 46, this being the commonest and most used form of joint and being entirely suitable for the majority of seams. Where the plates lap further and two rows of rivets are used, as in Fig. 47, it is called a "double-riveted lap joint", this type being used for moderately heavy plates or for high pressures. If the plates are brought together edge to edge and a cover plate put on one side as in Fig. 48, it is known as a "butt joint with a single strap" and is frequently used for the lengthwise seams of tanks or boilers. For very high pressures and heavy plates the custom

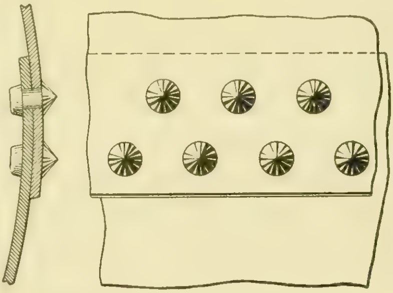


Fig. 47. Double-Riveted Lap Joint

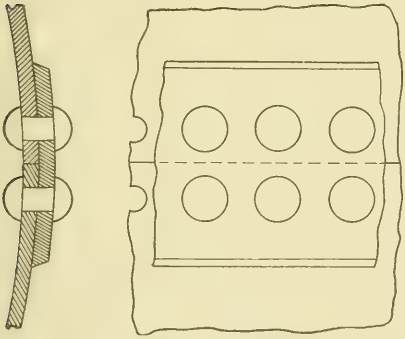


Fig. 48. Butt Joint with Single Strap

is to use a "butt joint with two welt strips", two rows or three rows of rivets being used through both plates and strips, and an additional row passing through the inner strip and plates only, Fig. 49. Other types of joints are sometimes used but these are the most common and most easily made. When a single butt strap is used, it is about $1\frac{1}{8}$ times the thickness of the plates but when two are used, the outer one is of the same thickness as the plate and the inner one is about $\frac{3}{4}$ the thickness of the plate. Butt joints should be used for plates over $\frac{1}{2}$ inch thick, two strips being used. Lap joints are used for the girth or circumferential seams and butt joints with one or two straps for the longitudinal seams, Fig. 50. The lengthwise seams of a boiler have the greatest strain on them.

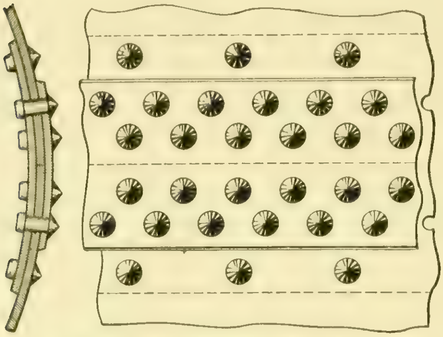


Fig. 49. Butt Joint with Two Welt Strips

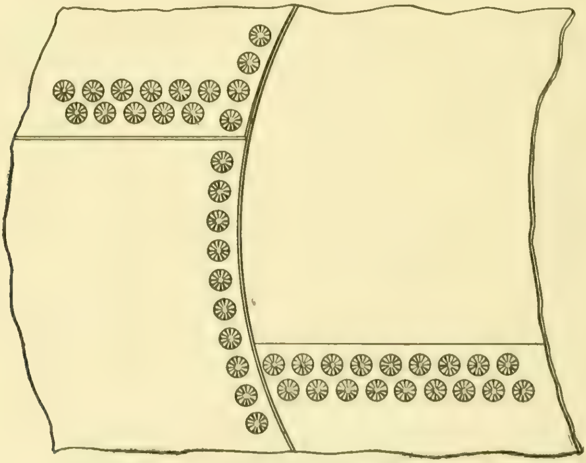


Fig. 50. Typical Boiler Shell Showing Method of Riveting

Strength of Joints. The strength of a riveted joint depends upon the materials used, the diameter and number of rivets, and the way in which the strain is applied to the rivets. The plate may break along the line of the rivet holes; or the rivet itself may shear off; or the plate may shear out in front of the rivet or it may simply crush in front of the rivet. Rivets should never be used where they are subjected to a tensile or pulling strain as their greatest strength is when in shear or crosswise strain. If they can be placed in double shear through using butt joints and butt straps on both sides, they work still better. Plates seldom shear in front of the rivets but sometimes they break along the line of the rivets and rivets sometimes shear off or pull out under heavy strains.

Table I gives the figures used by several boiler and tank makers for riveted joints and applies to single-strap butt joints and lap joints. The "efficiency of joint" indicates the relative strength of the joint and the rest of the plate, and is given as a ratio. The "pitch" indicates the distance between the centers of the rivet holes in the plate.

TABLE I

Efficiency of Single-Strap Butt Joints and Lap Joints

Thickness of Plate, Inches	Diameter of Rivet, Inches	Diameter of Hole, Inches	Pitch		Efficiency of Joint	
			Single, Inches	Double, Inches	Single	Double
$\frac{1}{4}$	$\frac{5}{8}$	$\frac{11}{16}$	2	3	.66	.77
$\frac{5}{16}$	$\frac{11}{16}$	$\frac{3}{4}$	$2\frac{1}{16}$	$3\frac{1}{8}$	.64	.76
$\frac{3}{8}$	$\frac{3}{4}$	$\frac{13}{16}$	$2\frac{1}{8}$	$3\frac{1}{4}$	.62	.75
$\frac{7}{16}$	$\frac{13}{16}$	$\frac{7}{8}$	$2\frac{3}{16}$	$3\frac{3}{8}$	.60	.74
$\frac{1}{2}$	$\frac{7}{8}$	$\frac{15}{16}$	$2\frac{1}{4}$	$3\frac{1}{2}$	.58	.73

When laying out plates and riveting, care should be taken to see that the various longitudinal seams do not come in line with each other, but that they are offset, or staggered. The inner plate of the longitudinal seam should be hammered thin at the edge where it comes to the circumferential or girth seam so that the rivets can draw the plates tightly together at all points; otherwise there will be leakage.

When rolling iron and steel plates, there is a fiber formed lengthwise of the plates in the direction they are rolled and, when making boilers or tanks, it is important that this fiber should run around the boiler in the direction of the girth seams to get the greatest strength. When ordering plates, it is customary to give that dimension first which indicates the way the fiber must run. When plates are to be flanged or turned up around the edge, as for heads of tanks or boilers, the curve at the corner should have a radius equal to at least four times the thickness of the plate and the material should be of the best quality. Marine boilers sometimes have the edges of the shell flanged inward and a flat plate used for the head, but this method is more expensive than flanging the head for most work.

Calking. Calking is the operation of closing the edges of a riveted joint to make the plates fit tight and give a good joint. A round-edged tool, Fig. 51, is driven against the edge of the overlapping plate so as to make it flow down against the other plate and close up any space between them at the edge. Unless this operation is properly done, however, the seam may be opened instead of closed and the joint be made worse than before, and this is one of the operations that is being superseded by electric welding. Electrical calking is done by using a metallic electrode and depositing metal along the edges of the plates by means of the heat from an arc, thus covering the joint and drawing the two plates together, Fig. 81.

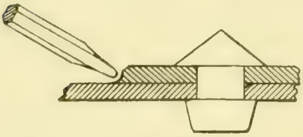


Fig. 51. Calking a Riveted Seam

Riveting Tools. The tools required for riveting consist of hammers, calking tools, rivet sets for forming the heads, rivet heating furnaces, punches, shears, drills, drifts for drawing the holes in line, and, in some cases, pneumatic or hydraulic riveting machines. For the average small shop it will be sufficient to have hammers, heaters, shears, punches, and drifts, with a set or two for the heads. The use of drift pins for drawing the holes in line is very common practice on cheap work but should never be done on a good job as it distorts the holes and prevents the rivets from filling them. Punched holes should not be used for good work as this operation is liable to injure the plates. Drilling is preferable, especially for steel plates.

ELECTRIC-ARC WELDING AND CUTTING

Historical. The use of the electric arc as the source of heat for joining and melting metals is one of the oldest applications of electricity and yet it was not developed to a commercially practical point until within a comparatively few years. In 1786, Martinus van Marum published a book, in Leipzig, describing some early electrical experiments, and, in this book, he gave an exhaustive treatise on the melting of metals by means of the electric current. In 1810, Sir Humphrey Davy, the versatile English scientist, described some experiments made in London with various metallic bodies, and, in 1815, J. G. Children of Londen described a process for welding iron wire with the electric arc obtained from batteries. From then until now, the development of the art of electric welding has progressed steadily, so that today it stands as the most universal of all welding systems and is being adopted rapidly for all classes of metal manufacture and repair. The men who have done most to perfect electric-arc-welding processes are De Meritens, Bernardos, Olszewsky, Coffin, Zerener, Slavianoff, Howard, and a few others of lesser importance, and further reference to the processes developed by some of them will be made.

Characteristics of the Electric Arc. The electric arc has probably been given more careful study and investigation than any other electrical phenomenon and yet there is comparatively little exact knowledge available regarding some of its most important characteristics. The exact temperature of an arc has never been determined although the most refractory substances may be melted in its vapor and, since the vapor is so hot, it is a very efficient source of heat. The temperature has been variously estimated at from 2000 degrees centigrade by some scientists up to 6000 degrees centigrade by others, but the temperature generally accepted as correct is about 4000 degrees centigrade. As long ago as the year 1840, Grove discovered that the current flows more easily from metal to carbon than in the reverse direction and that the current through an arc is greater, when passing from an easily oxidized metal to one that is not, than when flowing in the reverse direction.

The explanation of this is comparatively simple. The conductivity of an arc depends largely upon the kind of vapor in the arc and, to some extent, upon the ease with which the cathode (negative electrode) can be kept at a high temperature. If the anode (positive electrode) gives off a conducting vapor when heated, this vapor will help the conductivity of the arc. In the arc-welding systems in commercial use today, the arc is drawn between metal and carbon, or between metal and metal and, since the positive electrode or terminal of an arc reaches a higher temperature than the negative electrode, it is more efficient to use the article worked upon as the positive electrode of the arc. Since iron is more easily vaporized than carbon, the current flows more easily from iron to carbon than the reverse, because there is more iron vapor than

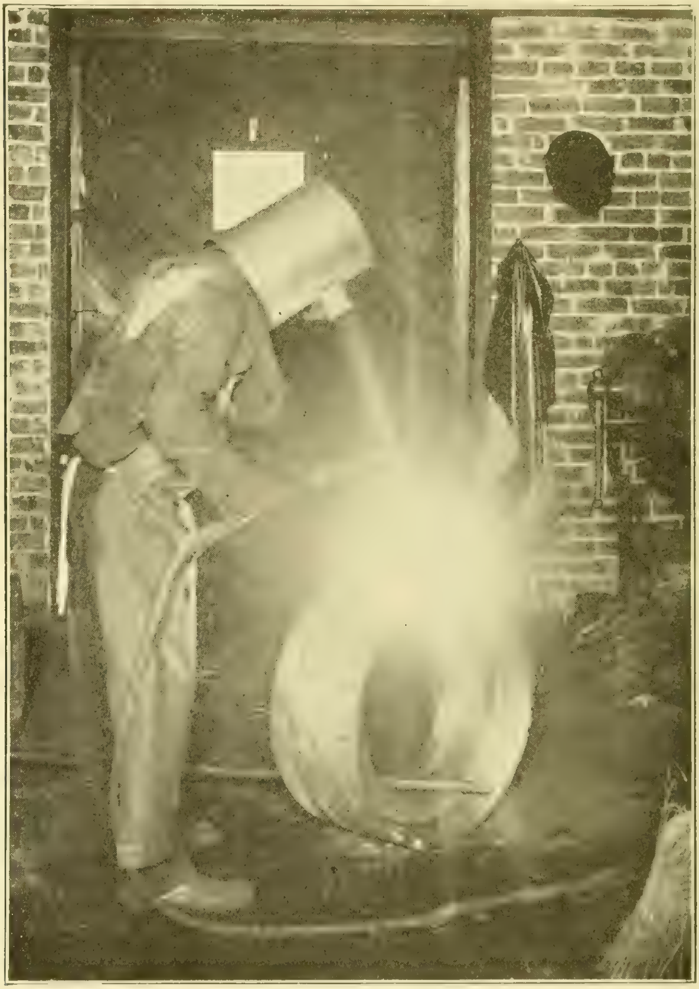


Fig. 52. "Striking the Arc"
Courtesy of Westinghouse Electric and Manufacturing Company

carbon vapor in the arc. This is proved by the fact that it requires more voltage to send a given current through an arc between carbon electrodes than between iron ones. It is also important that the negative electrode be kept at a high temperature and the usual practice of having the negative electrode small (due to the use of a wire or carbon pencil) makes this easily possible.

ELECTRIC WELDING PROCESSES

General Features. The process of welding or cutting with the electric arc is possible with nothing more than a source of current at a suitable voltage, some means for regulating the amount of current flowing, and an electrode. Practice has shown, however, that certain other devices are necessary, if satisfactory welding is to be done; and it is the determining of these devices and their proper uses that constitutes the main differences in the various processes used today. In order to do welding or cutting with the arc it is necessary first to connect the work to the positive side of the power-supply circuit and the electrode to the negative side of the circuit, by means of wires or cables, and to insert a regulating resistance in either of these circuits to limit the current flowing to the proper amount. The negative electrode should then be placed in contact with the work and quickly withdrawn, thus establishing the arc, Fig. 52, which provides the temperature required. As the metal soon begins to melt the work may begin at once.

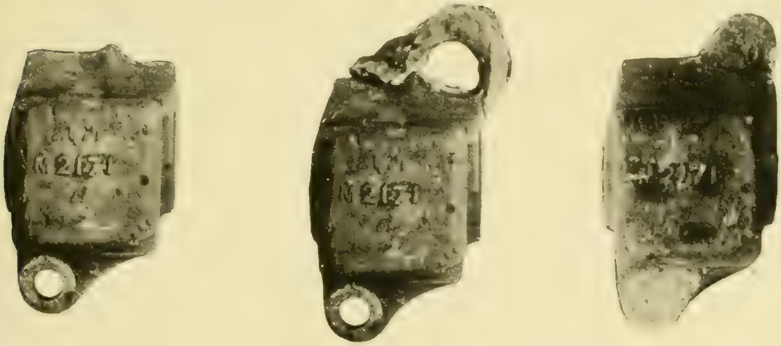


Fig. 53. Arc-Welding Lug on Steel Casting
Courtesy of Westinghouse Electric and Manufacturing Company

In general, electric-arc welding consists in using the heat of the arc to fuse or melt the filling material into the place to be filled,

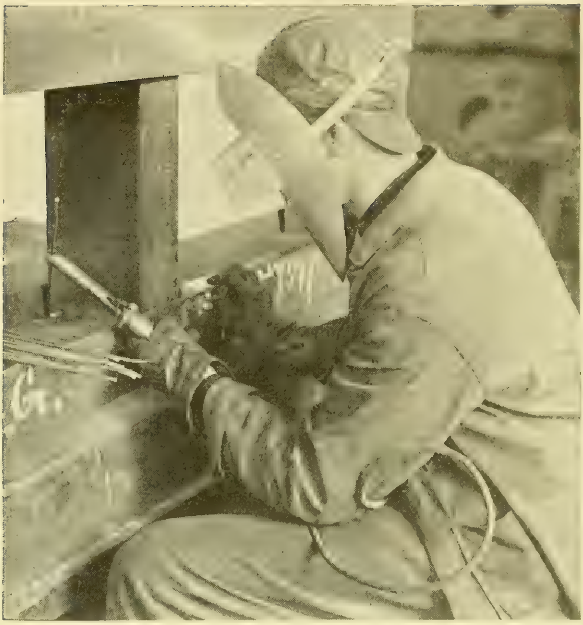


Fig. 54. Operator Using Metallic Electrode
Courtesy of C & C Electric and Manufacturing Company

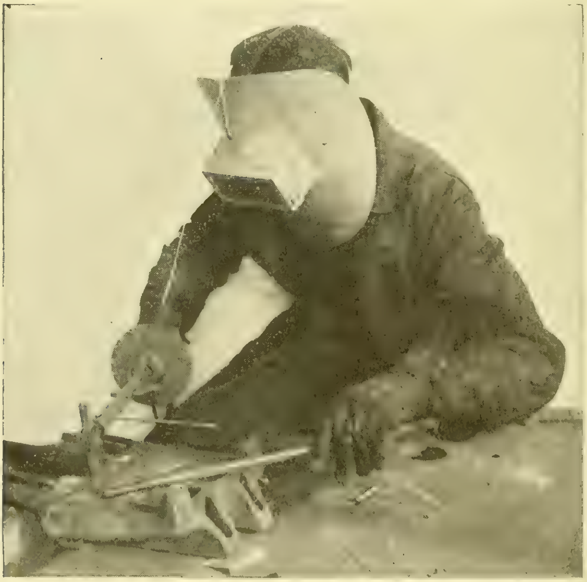


Fig. 55. Operator Using Graphite Electrode
Courtesy of C & C Electric and Manufacturing Company

Fig. 53, although the article worked upon may be melted down sufficiently to fill the space, if it is large enough at the point to be welded. Two methods or processes of using the arc for welding are in commercial use today, these being the "metallic" and the "graphite" processes. The metallic welding process, Fig. 54, consists in using a piece of wire as the negative electrode of the arc and fusing it into place; the graphite process, Fig. 55, consists in using a piece of carbon or graphite as the negative electrode and fusing a piece of metal into place by the heat of the arc, similar to a gas process. The graphite process is always used for cutting, a slot being melted through the piece to be separated. There is also a third system which will be described later, but it is not used much in the United States.

Benardos System. The Benardos system of electric-arc welding is based upon the use of a carbon pencil as the negative electrode and the article worked upon as the positive electrode, using for the purpose a continuous, or direct, current at a moderate voltage (usually from 60 to 70 volts). After the arc is established by touching the electrodes together and withdrawing, a piece of the filling material in the form of a "melt bar" is fused into place by the heat of the arc. Any metal, which does not volatilize or burn up too easily at the temperature obtained, may be welded by the Benardos process and this process is the best to use for cast iron, the copper alloys, and aluminum. When using the graphite pencil, it is necessary to give the hand a sort of rotary motion in order to cause the arc to play about over the surface of the job and prevent burning, for the arc never stops melting the metal so long as it exists. This motion also has the effect of causing any slag or impurities on top of the molten mass to flow off to one side, instead of remaining in the weld and spoiling its quality, and of distributing the heat more

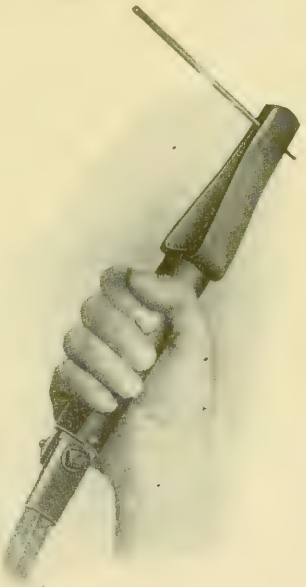


Fig. 56. Siemund Hand Electrode Holder
Courtesy of Siemund Wenzel Electric Welding Company

uniformly over the piece welded. When cutting with the arc, the article should be so placed that work can begin at the top and progress downward across the face of the piece.

Slavianoff System. The Slavianoff system of electric-arc welding is based upon the use of a metallic pencil, Fig. 56, as the negative electrode, and the article worked on as the positive electrode, and the use of a continuous current at low voltage. After the arc has been established by touching the electrodes together and separating them, as before, the negative electrode itself begins to melt and thus forms the filling material. This system is more successful for work with iron and steel electrodes than with the other metals, although many of them may be used where high-class work is unnecessary. The main application of this system has been to sheet-steel work, the metal electrode being deposited along the joint to be made and tying the two plates together so that they form practically one piece. This process may also be used for building up worn or missing pieces, filling holes, etc. The current required for the Slavianoff process is much less than that for the Benardos process but it is much slower for operations involving the placing of any very large amounts of metal quickly. The successful development of the Slavianoff system has been the principal cause for the recent rapid spread of electric-arc welding in the industries.

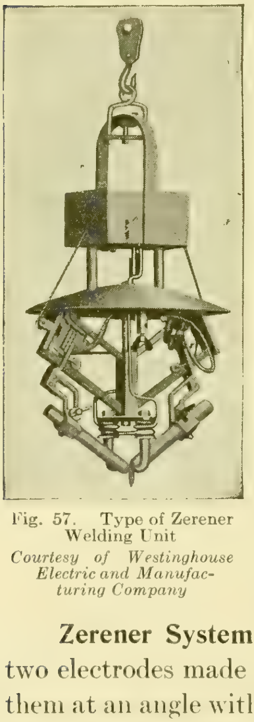


Fig. 57. Type of Zerener Welding Unit

Courtesy of Westinghouse Electric and Manufacturing Company

Zerener System. The Zerener system consists in having the two electrodes made of carbon and mounted in a frame which holds them at an angle with relation to each other and to the work, Fig. 57. The arc is drawn between them and is then deflected downward by a magnet and used in the same way as a gas flame. The apparatus for holding and feeding the carbon pencils is so bulky and complicated that this system has not been used in America to any great extent, although it is in use in several plants in Germany. The nature of the apparatus is such that large amounts of current cannot be used; so it is limited to comparatively light work. The weight and size of the holders for even moderate-sized work are such that they must be suspended from above by ropes and moved about over the work, although small holders for use in one hand have been developed for holding the lightest articles. The advantage claimed for this system is that the arc is controlled by a magnet and that finer work can be done.

ELECTRIC WELDING EQUIPMENT

Simple Equipment Wasteful. The equipment required for electric-arc welding depends largely upon the nature of the work to be done but, of course, the most complete apparatus does the best work, as in the case of any other sort of apparatus. The most elementary equipment consists of a barrel of water with two iron plates in it (using the resistance of the water to reduce the amount of current flowing) and an electrode holder, with some cables to connect the parts to the power circuit. This system can be used for cutting and for welding where roughness and uncertainty of results are no disadvantage. The current is varied by varying the space between the plates in the water barrel but this system is very wasteful and inefficient because the line voltage (usually 220 volts in shops and 550 volts for street railways) must be cut down to that required for welding (about 25 volts in the arc); this is done by dissipating the unused energy in the form of heat in the water. Sometimes resistances, made up of cast-iron grids, Fig. 60, are used instead of the water

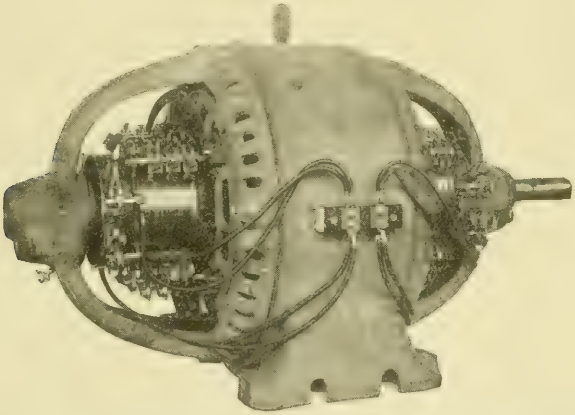


Fig. 58. 900-Ampere Welding Generator with Collector Rings at Each End for Taking Off Alternating Current
Courtesy of C & C Electric and Manufacturing Company

barrel, but they are more expensive and just as inefficient. This grid resistance is cut into and out of circuit by a series of switches.

Advantages in Low-Voltage Generators. The use of dynamo-electric machines of low voltage, Fig. 58, instead of resistances, as just described, is preferable because of their higher efficiency and the better voltage regulation obtainable. Fig. 59 shows a typical wiring diagram for the low voltage equipment. It is well known among electrical men that a motor-generator set gives the best regulation of voltage and, when the generator is compound-wound, we have the ideal apparatus for electric-arc-welding service. Therefore, the leading systems in general use today consist of motor-generator sets with suitable control apparatus for motor, generator, and welding circuits.

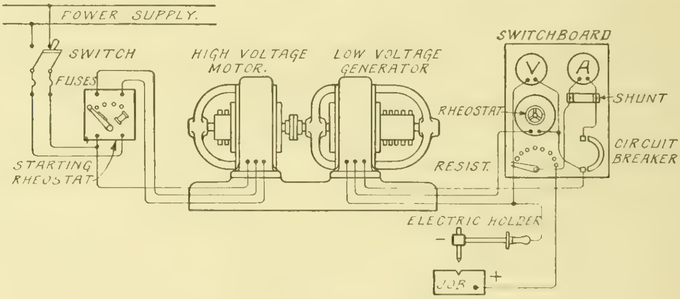


Fig. 59. Elementary Low-Voltage Arc Welding Equipment

Single-unit machines such as rotary converters, dynamotors, etc., are also used but are not so desirable where accurate regulation is necessary, as for thin sheet-metal work, etc. For work with the graphite electrode they are suitable and a large number of them are in use in foundries and other shops doing work on castings, and a few of them are in use on finer classes of work in shops where the load on the dynamotor is so low that the speed does not fall off and reduce the voltage enough to affect the work adversely.

There are only five manufacturers of importance in the United States at the present time offering arc-welding outfits; four of these use generators of low voltage and the fifth uses iron grids to reduce the voltage. A sixth company offers a welding system which is made for them under patents owned by them and several other concerns have announced their intention of bringing out arc-welding equipments within short periods. Each of these companies offers its apparatus on the strength of some peculiarity of the controlling devices for the welding circuits or certain features of the machines furnishing the current; so we will examine each system in detail and see the points of similarity or difference.

Indianapolis Track Welder. The Indianapolis track welder,

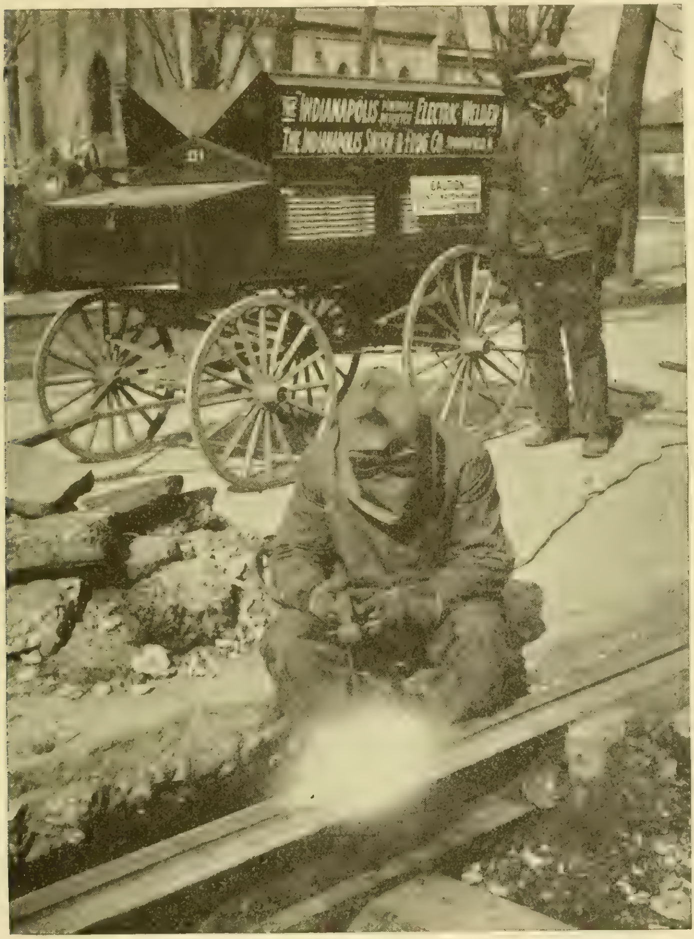

THE INDIANAPOLIS ELECTRIC WELDER
THE INDIANAPOLIS SWITCH & FROG CO.
CAUTION

Fig. 60. Portable Electric Welder in Action
Courtesy of Indianapolis Switch and Frog Company

Fig. 60, consists of a group of iron resistance grids mounted in a framework on a four-wheeled truck, with means for attaching to a trolley wire and the track; it is used mostly for repairs on street railway tracks, cars, etc., although it has been used for work of other kinds. The control device consists principally of a set of switches for varying the number of grids in series with the arc and an electrode holder with cables. The Benardos system is followed for most operations, although the Slavianoff system is used for rail bonding and car repairs. The advantage of this outfit lies in its low first cost but the extremely low efficiency of such a system prevents its use in industrial establishments. The diagram of connections, Fig. 61, shows the relation of the various parts of the circuit and the switches for cutting the resistance grids into and out of circuit to vary the current. No provision is made in this equipment for automatically regulating the welding circuit and it is possible to burn the work through getting too much current, if the circuit breaker should not open quickly on overload. The maximum current obtainable, however, is limited by the amount of resistance in circuit, so burned work is not liable to result excepting when most of the resistance is cut out. The nature of this system, as with water barrels, makes it necessary to have a separate outfit for each operator in order that each of them may adjust his current to suit the work in hand.

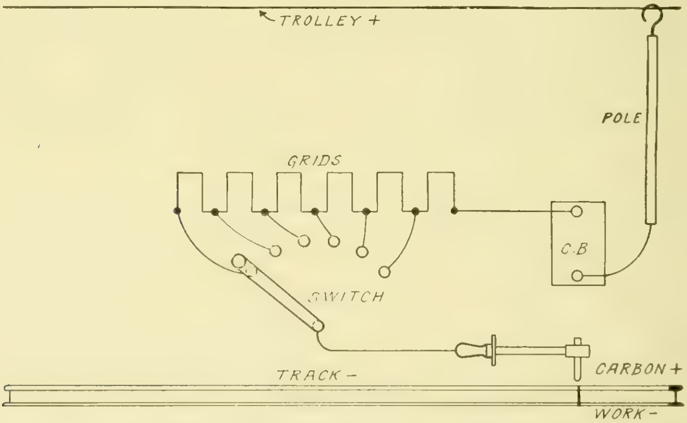


Fig. 61. Wiring Diagram Showing Principal Features of the Indianapolis Track Welding System

Westinghouse Arc Welder. The Westinghouse arc welder consists of a motor-generator set, with a switchboard for controlling the machine and the welding circuits. The generator is a 75-volt compound-wound direct-current dynamo and is direct-coupled to a motor of proper capacity and suitable for operation on the power circuit available. Being a constant-potential generator, several operators may work from it at once, if proper resistances and switches are provided for each circuit, and work may be done on either the Benardos or Slavianoff processes. No provision is made to limit the rush of current, when making contact between the electrode and the work when starting to draw the arc, although an overload circuit breaker is provided to prevent injurious overloads on the generator after welding is started. With this apparatus various classes of welding and cutting may be done; the positive line is connected to the work and the negative to the electrode holder in the usual manner. The amount of current required for the work in hand is regulated by a switch or series of switches which cut in or out sections of an iron grid resistance and a small portion of the resistance bank is left in circuit continuously to steady the arc. This apparatus has been used almost entirely for graphite cutting and welding until recently, when means were provided for using metallic electrodes also. The disadvantage of this outfit lies in the lack of protection for the work against burning when the arc is struck and the necessity of the operator's closing the circuit breaker whenever an overload causes it to open. The advantages lie in the use of a compound-wound generator and a separate motor and

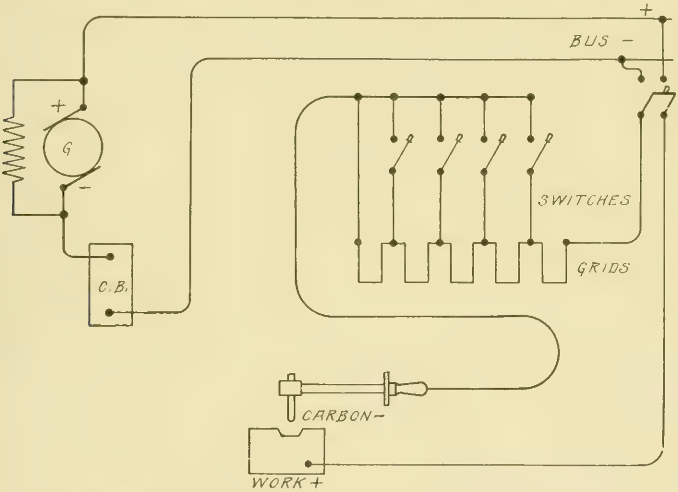


Fig. 62. Wiring Diagram for Westinghouse Arc Welder

the ability to supply several welding circuits at the same time. These makers also supply a shunt-wound generator for use on a single welding circuit, but this does not offer such accurate voltage regulation as the compound-wound dynamo. Fig. 62 shows the principal elements properly connected, for a single operator, and more circuits would involve the addition of the extra switches, resistances, and electrode holder for each of them. The apparatus for controlling the machine and the welding circuits is mounted on a switchboard which is stationed near the motor-generator set.

Lincoln Arc Welder. The Lincoln arc welder is similar to the equipment made by the Westinghouse Company except that a single-unit machine is used instead of the customary motor-generator set, as will be seen from the wiring diagram, Fig. 63. This machine is either a dynamotor for use on direct-current circuits or a synchronous converter for alternating-current circuits and current is generated by it at 75 volts for welding. In one form of this machine the current is varied by changing the strength of interpoles, cutting out certain sections of the windings with suitable switches, but the arc is so sensitive that the current will vary over a considerable range, if the operator's hand is not steady. With the other machines a resistance is used to vary the current in the usual manner and an overload circuit breaker is provided to protect the machine from dangerous overloads due to short

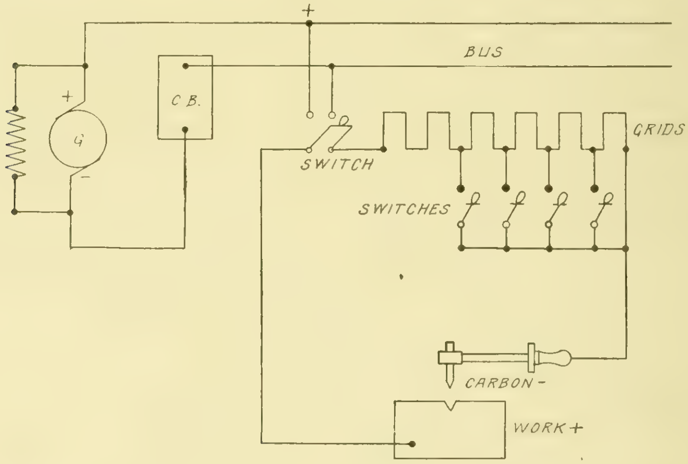


Fig. 63. Wiring Diagram for Lincoln Arc Welder

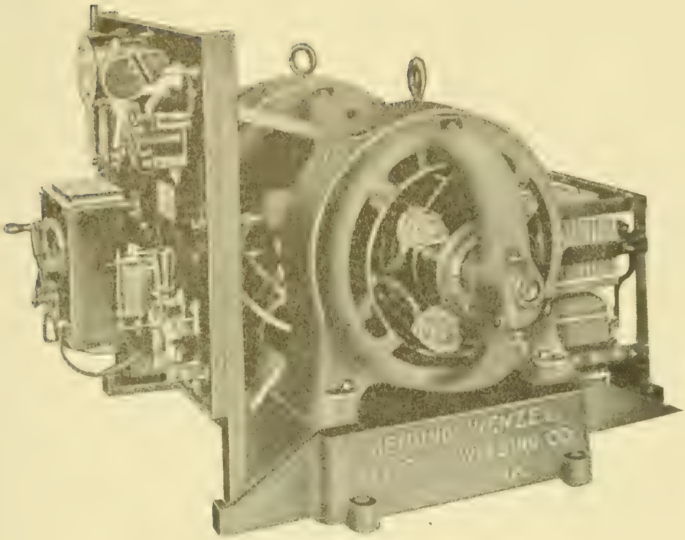


Fig. 64. Single Welder Siemund Wenzel Unit

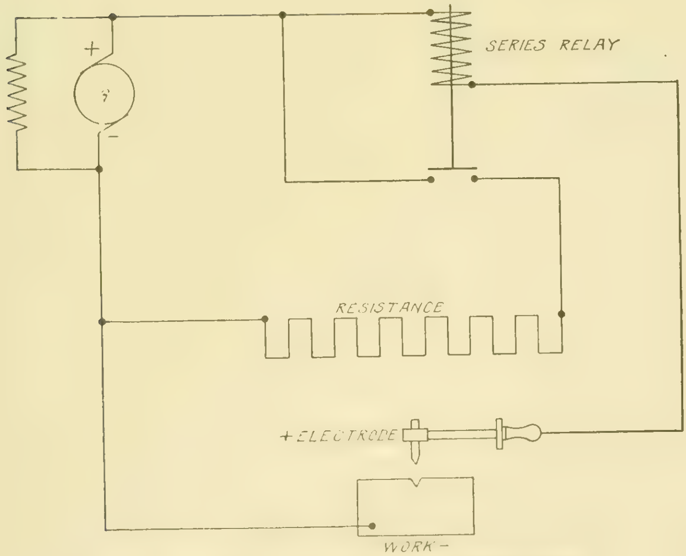


Fig. 65. Wiring Diagram for Siemund Wenzel System

circuits. No provision is made, however, to protect the work from burning, when starting to weld, and the circuit breaker must be closed by hand. The advantage of this equipment lies in the lower cost of the single machine than for a motor-generator set, although the voltage regulation is not so good; the work is done by both the Benardos and Slavianoff processes and the aparatus is used considerably in foundries and other places where variations in the voltage cause no harm.

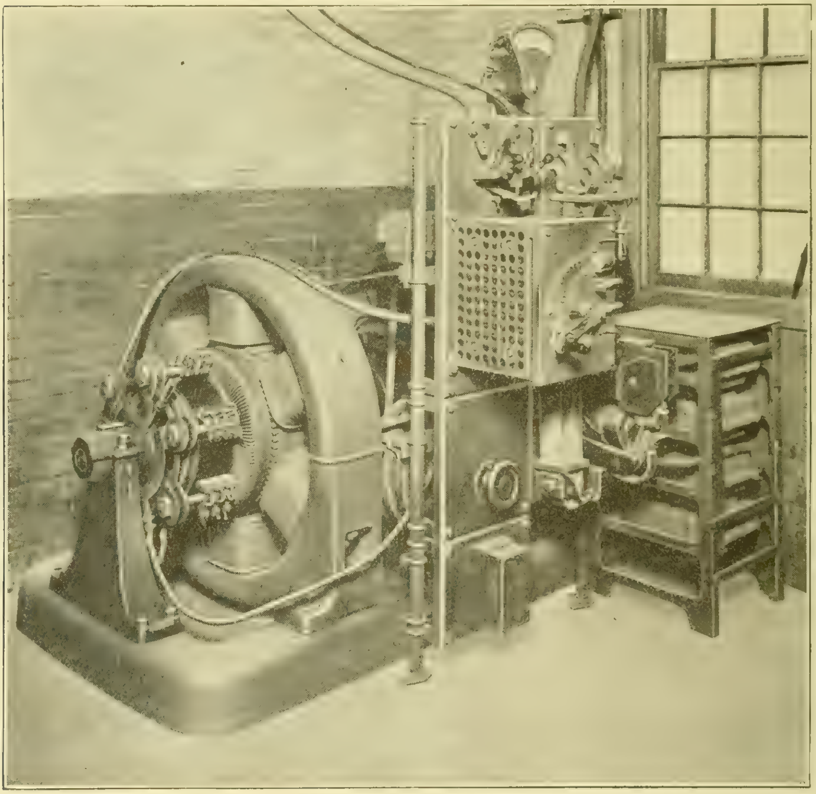


Fig. 66. Arc Welding Set with Automatic Overload Relay
Courtesy of General Electric Company

Siemund Wenzel Welding System. The Siemund Wenzel welding system is based upon the use of a single shunt-wound generator, Fig. 64. for each welding circuit and operates on the Slavianoff system. The principal feature of this system lies in having the generator operating at full load all of the time and using the current in the arc when welding, or dissipating the energy through a resistance in the form of heat when not welding, Fig. 65. The circuit is thrown from the arc to the resistance by means of a solenoid switch. The disadvantage of this system lies in its low efficiency because of the large amount of energy wasted in the resistance, when not actually welding, but its promoters claim they can do better work with it because of the smoother load curve. They also use an electrode holder with a coil around it to create a magnetic flux about the arc, on the theory that it helps in depositing the

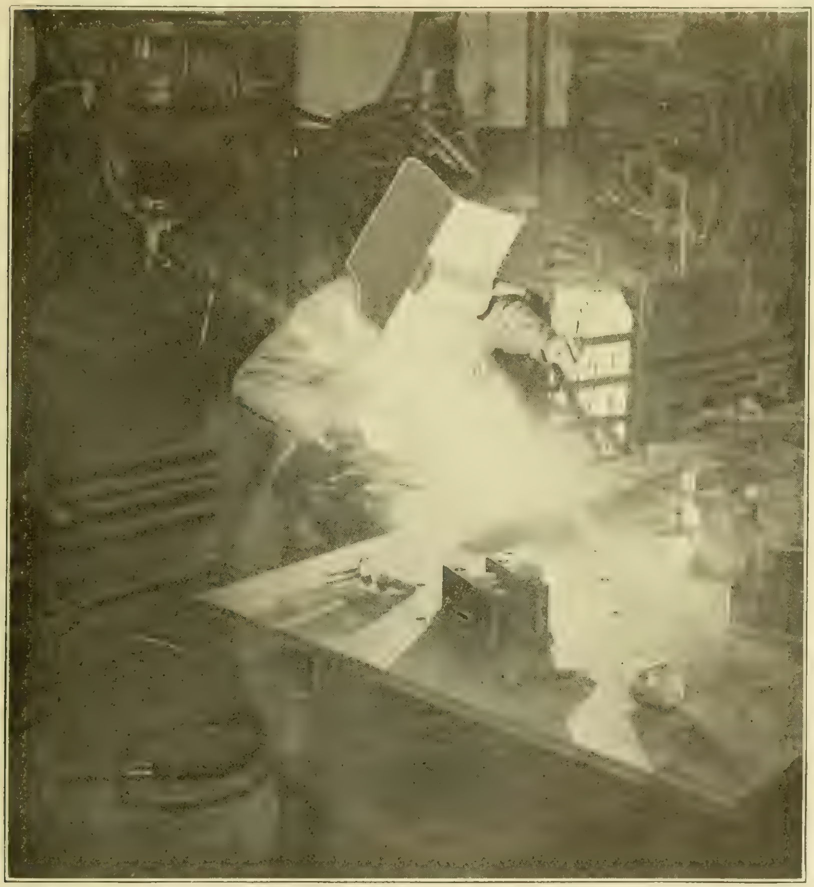


Fig. 67. Operator Using Graphite Electrode on Medium Work
Courtesy of General Electric Company

molten metal. This is a doubtful advantage because molten iron and steel are non-magnetic.

General Electric Arc Welder. The General Electric arc welder, Fig. 66, has been developed to a higher degree than the others previously mentioned because an automatic overload relay is used to insert a protective resistance in case of prolonged overload, but no provision is made to prevent burning the work when drawing the arc. This apparatus is good for moderately heavy work, Fig. 67, but would probably not do as smooth work in light materials as the gas systems. The apparatus consists of a compound-wound low-voltage direct-current generator, similar to those previously described, direct-coupled to a motor of proper type to suit the power supply, together with a switchboard containing the necessary devices for controlling the machine and the welding circuits. By reference to Fig. 68, it will be seen that the current flows from the positive side of the generator to the work through a bank of resistance grids; thence through the arc, electrode, and series relay coil, and back to the generator negative. A contactor and relay act as protective devices for cutting in resistance in case of serious overload, and a switch is provided for varying the amount of resistance in order to regulate the amount of current flowing through the arc. Several men can work at once from the generator, because

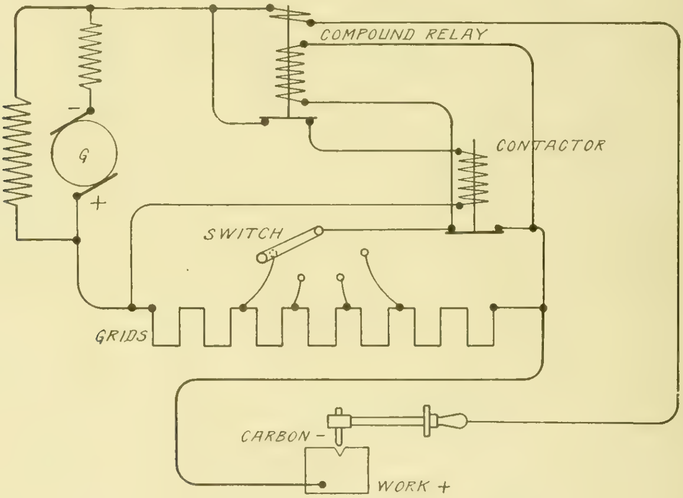


Fig. 68. Wiring Diagram for General Electric Welding System

it is a constant voltage machine, by adding enough circuit-controlling relays and contactors. The advantage in this system lies in having an automatic relay for cutting in the protecting resistance, instead of allowing the overload to become heavy enough to injure the generator, and also because it is not necessary for the operator to go to the switchboard to close the circuit breaker. The disadvantages lie in having no means for protecting the work from the burning effect of the rush of current when drawing the arc, and in the necessity of using a time-limit relay for the overload coil. It is evident that, if an instantaneous relay is used, it will open every time the current reached a certain maximum, thus insuring protection to both generator and work and eliminating roughness of work. This apparatus is satisfactory for use in foundries and in scrap yards for cutting with the graphite electrode, and for the coarser kinds of metallic welding. A portable outfit is shown in Fig. 69.

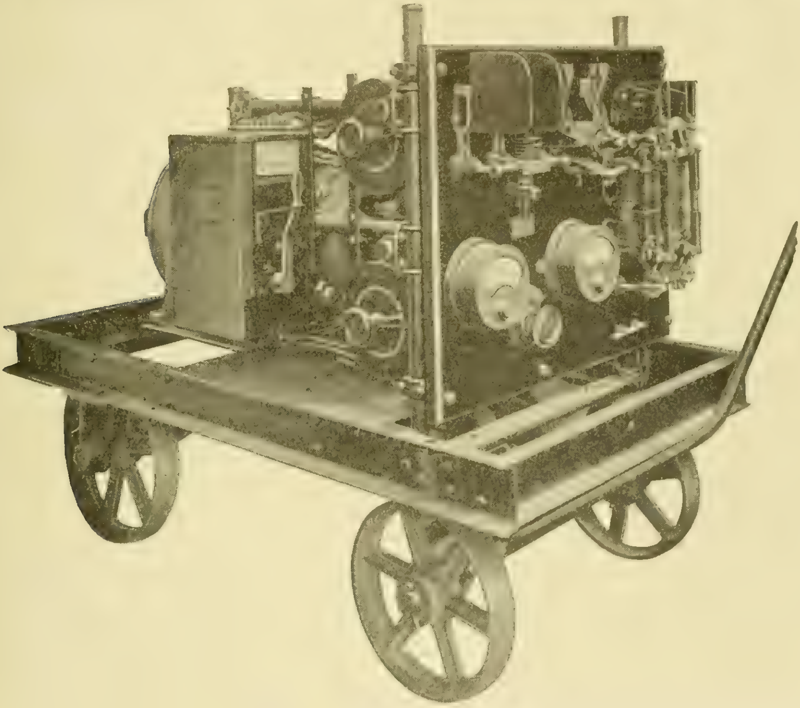


Fig. 69. Portable Welding Outfit
Courtesy of General Electric Company

C & C Electric-Arc Welding System. The C & C system of electric-arc welding has been developed through a longer period than any of the others and, consequently, has its control system developed to a higher degree. The apparatus consists of a low-voltage generator direct-connected to a suitable motor, Fig. 70, mounted on a cast-iron base, and specially constructed for the heavy duty imposed by arc welding. For controlling the welding machine, line, and motor a switchboard is supplied, which may be mounted in any convenient position with relation to the machine. On this panel are the necessary instruments and switches for the welding machine, and the apparatus for controlling the welding circuits is mounted on separate panels. Each welding panel contains one set of their patented automatic control systems, and means are provided for preventing a rush of current, when drawing the arc, as well as for inserting a protective resistance in case of dangerous overload, when using the graphite arc. By this means the thinnest metals, Fig. 71, or the heaviest castings or forgings, Fig. 72, may be welded safely and smoothly and the operation of the relays is entirely automatic so that the operator does not have to go to his panel and close circuit breakers, etc., after starting his work. The diagram of connections, Fig. 73, shows just how the various devices occur in the circuit; it will be seen that the energizing coil of the magnetic contactor is in parallel with the arc. When the series relay closes the circuit through this

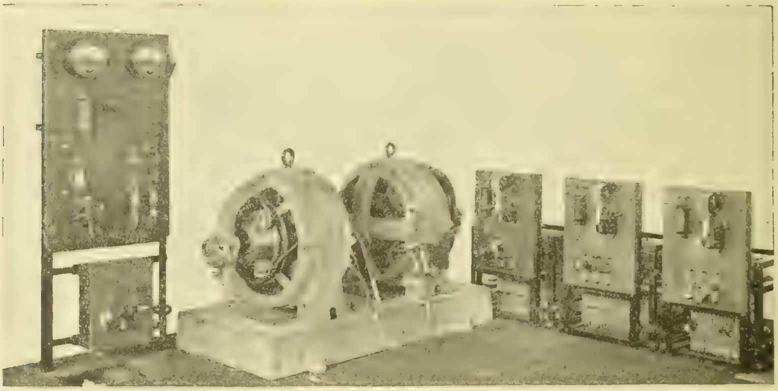


Fig. 70. 300-Ampere Welding Set with Control Panel and Auxiliary Welding Panels
Courtesy of C & C Electric and Manufacturing Company

coil, the path through the electrode and work offers less resistance and the coil does not get sufficient current to close the contactor; as soon as the arc is drawn, however, that path becomes of higher resistance and the coil is energized enough to close the contactor and cut out starting resistance. This allows just the right amount of current to flow and work proceeds until finished. In case of overload while working, the overload relay causes the contactor to open and insert protective resistance until the overload is removed but does not rupture the arc and stop work. This system is made for operation on both the Benardos and Slavianoff processes and more of them are in use in this country than of all other types of apparatus combined.

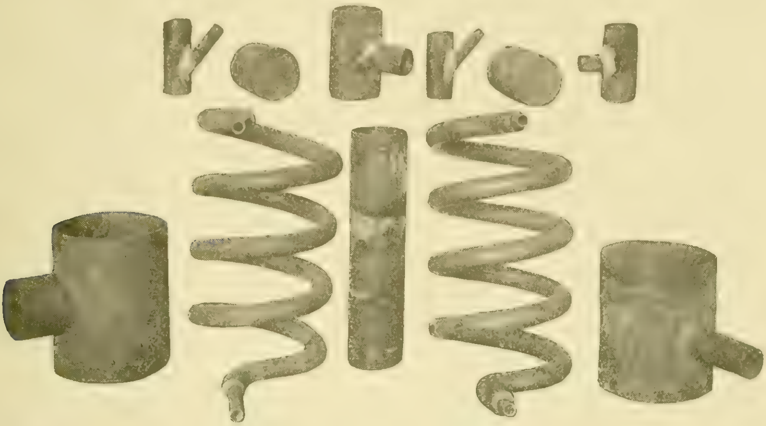


Fig. 71. Miscellaneous Pipe Welds with Light Tubing
Courtesy of C & C Electric and Manufacturing Company

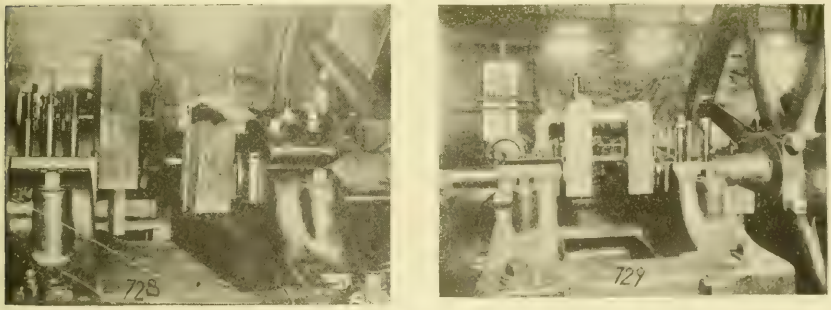


Fig. 72. Broken Steel-Forged Crankshaft Welded with Graphite Electrode
Courtesy of C & C Electric and Manufacturing Company

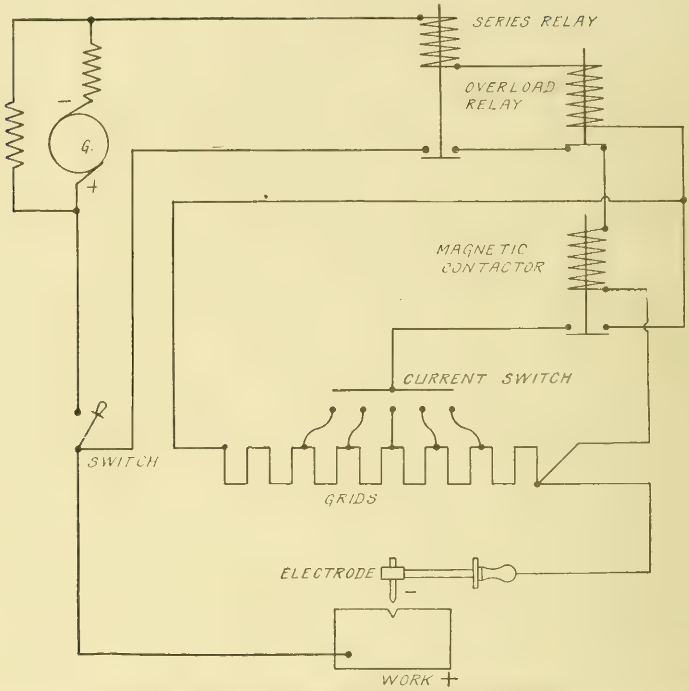


Fig. 73. Wiring Diagram for C & C Welding System

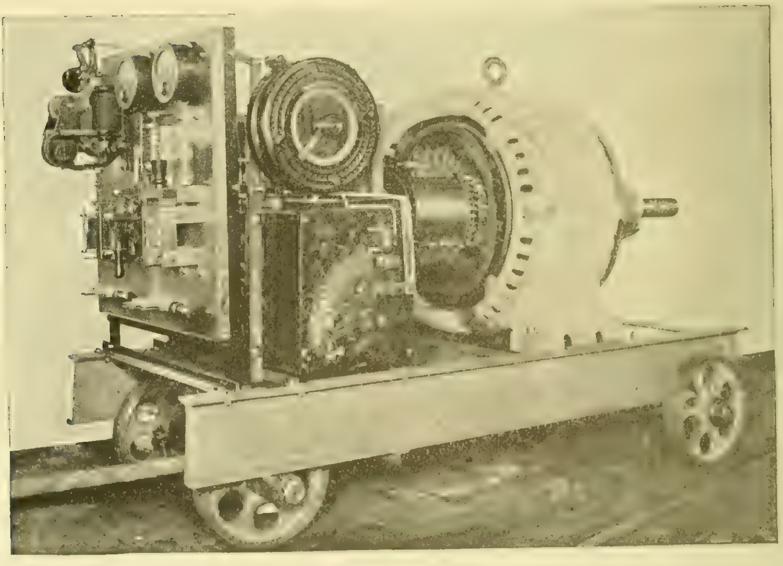
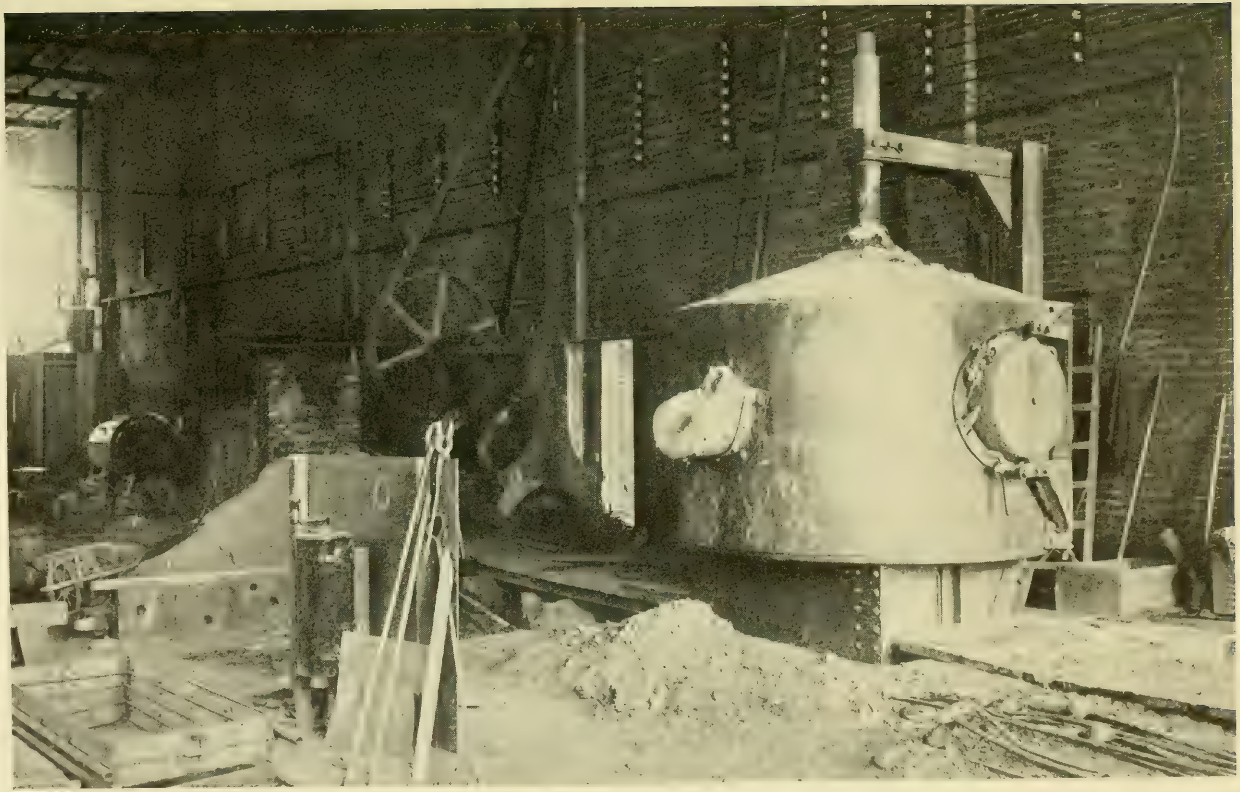


Fig. 74. 600-Ampere Portable Single-Unit Welding Outfit
Courtesy of C & C Electric and Manufacturing Company



MODIFIED GIROD ELECTRIC FURNACE INSTALLED FOR CHICAGO ELECTRIC CASTINGS COMPANY

Courtesy of the Iron Age

Owing to the use of a separate panel for each welding circuit, it is possible to have as many operators working at once as conditions may require, tapping each panel off of the distribution circuit like so many motors; the only limitation is that the generator shall be of sufficient capacity to furnish the current required. The advantage of this system over the others lies in the means for automatically reducing the current when drawing the arc, automatically increasing it to the desired amount after the arc is established, and automatically reducing it in case of overload. Fig. 74 shows a portable equipment arranged for both graphite and metallic circuits. Work done with C & C apparatus is practically as smooth as that done with gas and the only limitations are those imposed upon all arc-welding systems by the high temperature. This means that such metals as zinc, silicon, manganese, etc., are volatilized or burned out of the alloys at the high temperature, if the arc remains too long on the work. It is important that the proper methods be used, when working in metals containing them, as will be described later this limitation is not peculiar to the C & C system, but applies with equal force to all of them.

Quasi=Arc=Welding Method. An English system known as the "quasi-arc-method of welding" has been used to a limited extent abroad, but has not been received very kindly in America because of the expensive electrodes used. This is based upon the use of wires or electrodes coated with a flux for preventing oxidizing on the theory that, if the air is kept away from the molten metal, there will be no chance for the oxygen in the air to combine with the carbon in the metal and cause trouble. While it is true that the flux protects the work to the extent of giving clean welds, it is also true that hundreds of welds are made every day without flux which give most satisfactory results.

Kjellburg System. The Kjellburg system is also based upon the use of a flux on the wire and the users of it make some very strong claims for it, but experience shows that work can be done satisfactorily without flux for every kind of welding except iron castings, and the idea of expensive special electrodes is not very satisfactory to the operators With both of the above types of electrodes, any of the apparatus described may be used.

WELDING OPERATIONS

Amount of Current Used. Welding operations are of various kinds and take different amounts of current, depending upon the nature of the material worked upon, the size and shape of the piece, and the sort of operation to be performed. For example, thin steel sheets require less current than thick ones; cutting requires a larger amount of current than welding, etc. As a general rule it may be said that metallic welding operations usually require from 50 to 150 amperes, although thin sheets may be welded with as little as 15 amperes and extra heavy ones may take 185 or 190 amperes; graphite arc welding, on the other hand, averages from 350 to 500 amperes, running from 100 amperes on small articles up to 600 amperes on heavy work. Cutting with the electric arc requires from 300 amperes on small sections up to 1000 amperes or more, the average job taking from 400 to 600 amperes. The nature of the equipment supplying the energy will affect the amount of current required to some extent, those with the best control systems being the most economical.

Plate Welding. The rate at which welding can be done depends upon the article to be welded, its size and shape, material, nature of weld, etc., Table II indicates the speed of welding seams in sheet steel.

TABLE II

Data on Steel Plate Welding

THICKNESS	DIAM. ELECTRODE	AMPERES	SEAM WELDED
28 to 20 gage	18 B. W. G.	10 to 25	30 ft. per hour
18 gage to $\frac{1}{8}''$	$\frac{1}{16}''$ diam.	20 to 40	25 ft. per hour
$\frac{1}{8}''$ to $\frac{3}{16}''$	$\frac{3}{32}''$ diam.	30 to 60	20 ft. per hour
$\frac{3}{16}''$ to $\frac{1}{4}''$	$\frac{1}{8}''$ diam.	50 to 100	15 ft. per hour
$\frac{1}{4}''$ to $\frac{3}{8}''$	$\frac{5}{32}''$ diam.	75 to 150	10 ft. per hour
Over $\frac{3}{8}''$	$\frac{5}{32}''$ diam.	150 to 180	Variable

The figures given in the last column are only approximate, as they may easily be exceeded by an expert operator, but they give a fair average. These apply to seams made by butting the edges of the plates together and welding along in the space between them. The edges of the plates should be beveled sufficiently to allow the filling material to penetrate the full thickness of the plates, Fig. 75, or else a satisfactory weld will not result. Thicker plates than those given may also be welded and the time will vary as the square of the thickness. This is based upon one-fourth of an inch as the standard because that is about the thickest plate which may be satisfactorily welded by going along the seam but once. For thicker plates it is necessary to go along the seam several times in order to fill the slot properly and the area of the slot increases approximately as the square of the thickness when a V-shaped groove is to be filled. When an X-shaped slot, or two V slots, can be formed by beveling the plates on both sides, then the time required to make the weld is cut in two, and the rate of welding varies about in the same ratio as the thickness of the plates. The metallic electrode is used almost exclusively for steel plate and sheet welding, although the graphite electrode is sometimes used for heavy plates, when it is possible to work with the plates laid in a horizontal position, thus preventing the molten steel from running off.

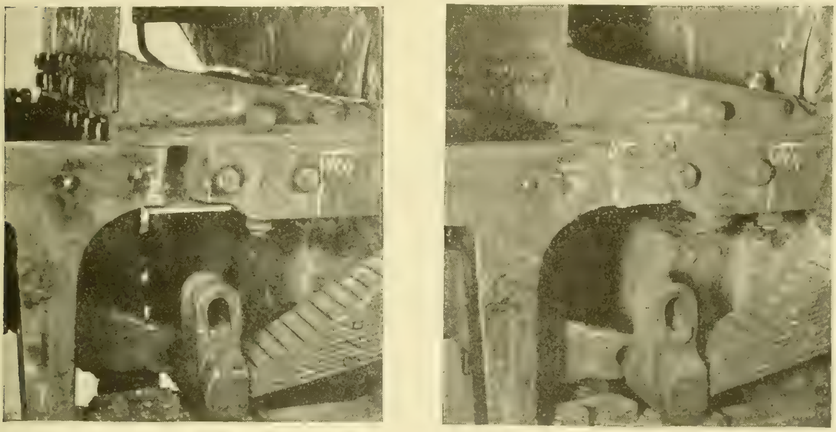


Fig. 75. Fractured Locomotive Side Frame Cut Out with Graphite Electrode and Welded with Metallic Electrode

Courtesy of C & C Electric and Manufacturing Company

Castings. When castings of iron or steel are to be welded, it is necessary to prepare a large enough space to work in; otherwise it will be impossible to join the pieces throughout their thickness. This is due to the fact that the filling material is not so liquid as that used with brazing and consequently will not flow in a small crack, but must be allowed to run easily into the space. With steel castings, and for some classes of small holes in large iron castings, the metallic electrode may be used but, for most cast-iron pieces and very large steel pieces, it is necessary to use the graphite arc and a melt bar for the best results. For cast-iron welding it is desirable to preheat all but the smallest and simplest pieces before welding in order that the high-shrinkage factor of the metal will not cause cracks when the weld is cooling. It is also good to reheat after welding and allow the piece to cool slowly in order to insure a weld soft enough to machine. A good welding flux is also an advantage when making cast-iron welds in order to help raise the slag and improve the quality of the weld. Iron with about 25 per cent of silicon should be used for cast-iron welding, and steel with from 25 per cent to 40 per cent excess of carbon, manganese, vanadium, or other desired content should be used when welding steel castings containing the elements mentioned.

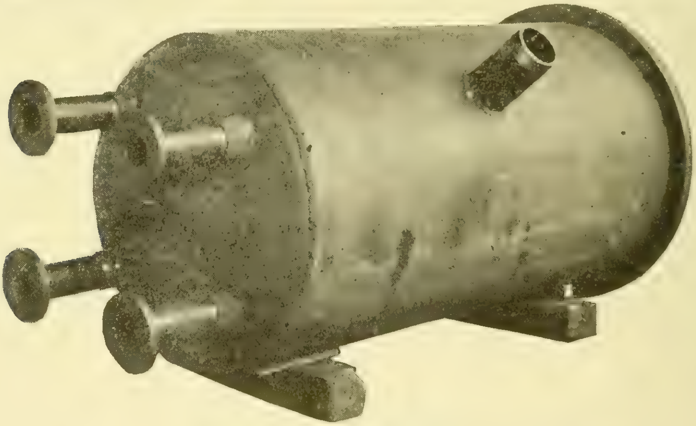


Fig. 76. Tank with Head, Flange, and Branches Welded in Place
Courtesy of C & C Electric and Manufacturing Company

Copper and Aluminum. Copper and aluminum sheets, bars, and castings may be welded with the electric arc by using the graphite electrode and puddling in the filling. This operation is similar to welding cast iron and can be done only with the work laid in a horizontal position to prevent running. Owing to the necessity for using the graphite electrode instead of a piece of wire, it is evident that thin sheets cannot be successfully welded by this process. But sheets over one eighth of an inch thick have been welded, both of aluminum and copper, and castings as thin as one-fourth of an inch also. It is necessary to build a simple mold of clay around the spot to be welded in order to hold the molten metal, but it is a very simple process and requires but the smallest amount of current which will melt the metal. Large amounts of current tend to burn the material and, if zinc is present (as in brass), it will volatilize or burn out and leave a porous and useless weld. The same thing applies to bronze alloys containing manganese, phosphorous, etc., but in a lesser degree. In other words, when welding alloys of any kind, it is necessary to use that current which is suited to the most volatile element in the mixture. The others will get heat enough to flow sufficiently for all practical purposes in most cases and experience will soon show any operator the best methods of handling any of the alloys.

Boilers and Tanks. Boilers and tanks offer one of the best fields for the application of the Slavianoff, or metallic welding, process and the adoption of this method in manufacturing, Fig. 76, as well as in repairing such articles instead of riveting them, Fig. 77, is proceeding very rapidly. Joints, which have been properly welded with a metallic electrode of suitable size and composition and with the right amount of current, will be stronger than riveted seams. If the joint is reinforced slightly by additional filling material, it will be stronger than the original plate but, even when ground flush with the thickness of the plates, it will show from 85 per cent to 90 per cent of the strength of the plates for thick stock, and up to over 95 per cent of the strength for thin stock. The various methods in use for welding the seams in tanks are shown in Fig. 78, those welded in two places being best for high pressure. These may be compared with the usual boiler riveted joints in Fig. 79. Since the strain on the longitudinal seams is double that on the circumferential seams, it is customary to lap-weld the side seams for strength. When the tank or boiler is intended for use under high pressures, it is better to lap all seams; then a butt strap is added to the side seams and welded at both sides and the center,

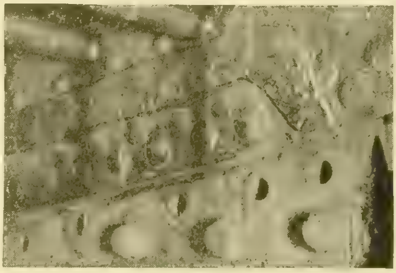


Fig. 77. Patch in Boiler with Seam Prepared for Welding

as indicated in one detail. The method of welding the head depends upon the shape of it, the convex head being the most common and flanged to slip inside the shell, and the welded seams are clearly indicated in the figure.

Boiler makers have been slower to take up electric welding than have the tank makers because greater restrictions having been imposed upon them in the interests of safety and reliability, they are generally more conservative. But there is a strong tendency now to use electric-arc welding to an increasing degree and boards

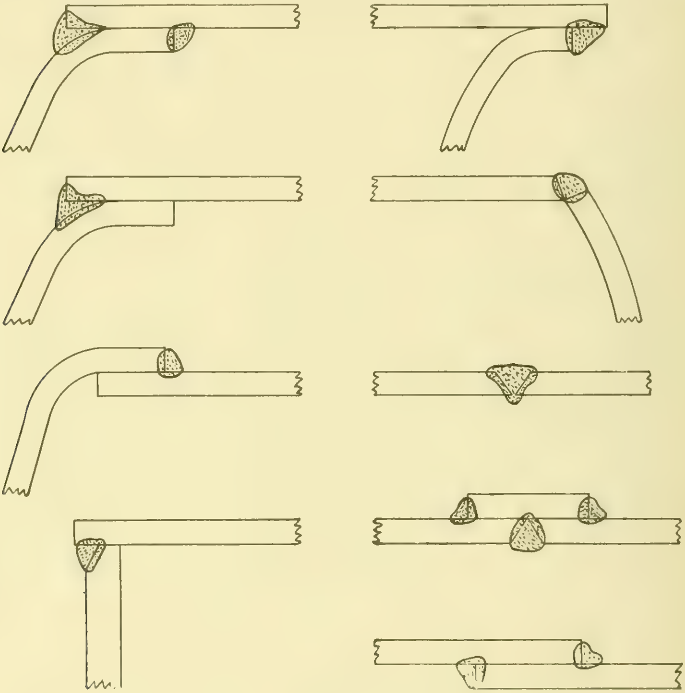


Fig. 78. Methods of Making Welded Seams in Tanks
Courtesy of C & C Electric and Manufacturing Company

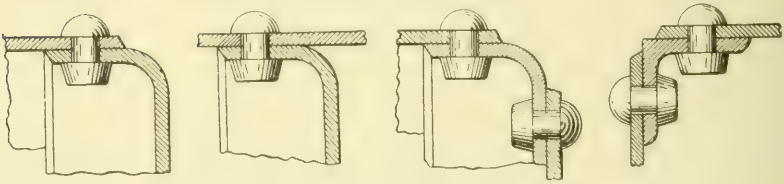


Fig. 79. Methods of Making Riveted Seams in Tanks

of inspectors and other official bodies are more liberal each year. By welding along the edges of the plates instead of calking with a hammer, Figs. 80 and 81, the plates are tied together and strengthened as well as tightened and the job never has to be gone over again. If the plates are badly corroded, they may be restored to their original thickness or to a greater thickness and leaking rivets may be tightened by welding around the heads and fusing them to the plates.

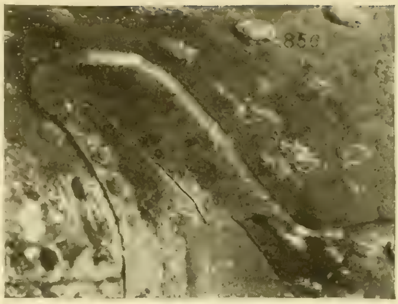


Fig. 80. Weld in Locomotive Fire Box
Courtesy of C & C Electric and Manufacturing Company

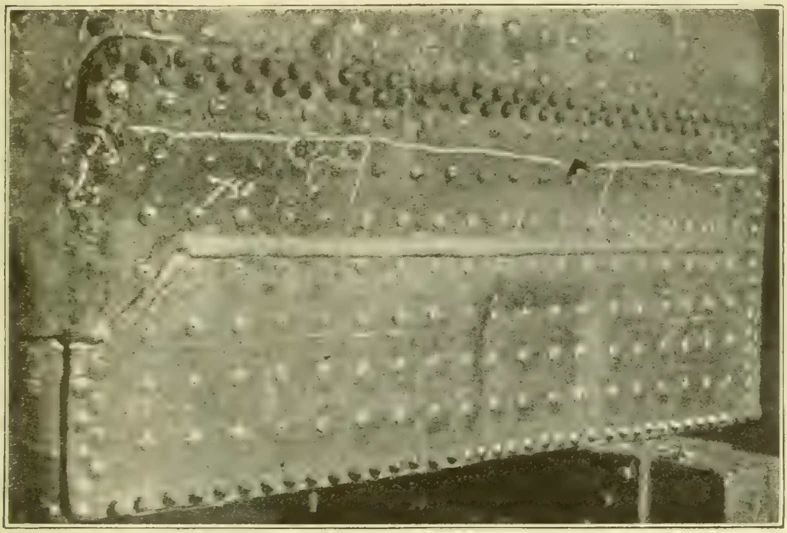


Fig. 81. Boiler Side Sheet Welded by Electric Welding Apparatus
Courtesy of The Boilermaker

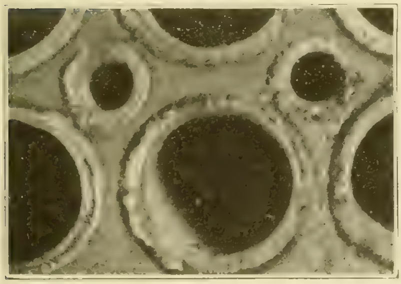


Fig. 82. Electrically-Welded Boiler Flues
Courtesy of Railway Master Mechanic

Welding Boiler Flues. One of the most important applications of metallic welding is in the welding of flues of locomotive boilers, Fig. 82. The flue end is expanded, beaded, and prossered in the usual manner, without the copper ferrule in the sheet, and then the edge of the bead is welded all around so as to attach it firmly to the sheet. This makes tubes and sheet one piece and eliminates leaking entirely, the life of the

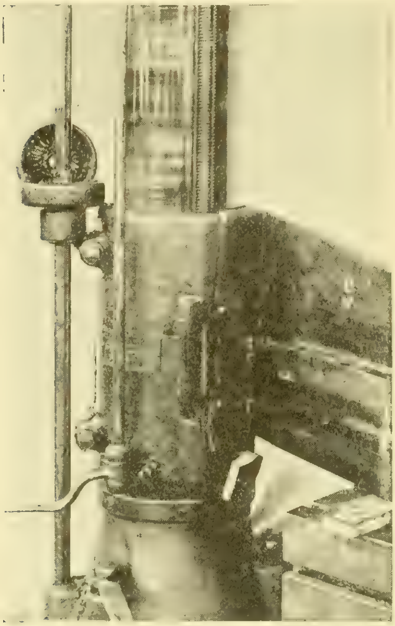


Fig. 83. Broken Housing of Radial Drill
Courtesy of C & C Electric and Manufacturing Company

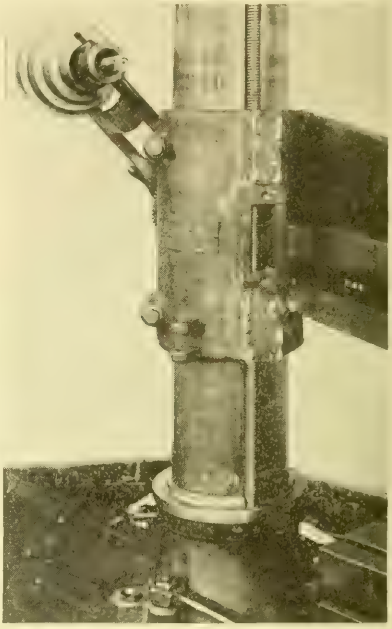


Fig. 84. Radial Drill Housing Welded with Graphite Electrode
Courtesy of C & C Electric and Manufacturing Company

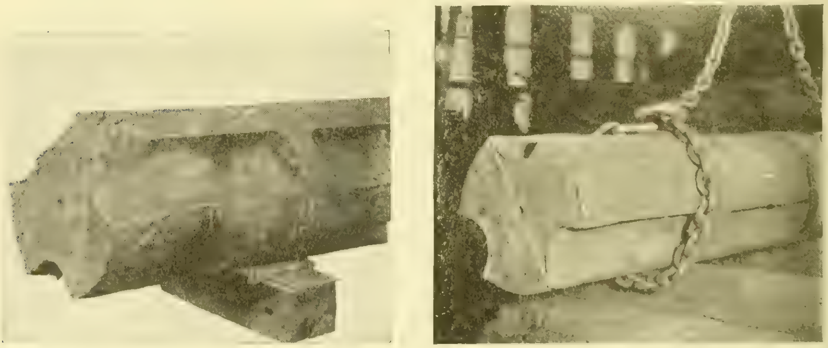


Fig. 85. Broken Steel Wabbler for Rolling Mill Welded with Graphite Electrode
Courtesy of C & C Electric and Manufacturing Company

TABLE III

Chemical Analysis of Iron and Steel Before and After Welding

Element	Sample No. 1, Iron		Sample No. 2, Steel	
	Per Cent Before	Per Cent After	Per Cent Before	Per Cent After
Silicon	0.009	0.003	.004	0.00
Carbon	0.015	Trace	.048	0.25
Sulphur	0.025	0.020	0.04	0.04
Phosphorus	0.068	0.043	0.08	0.07
Manganese	0.64	0.27	0.50	0.25
Iron (by difference)	99.108	99.664	98.86	99.39
Total percentage	100.000	100.000	100.00	100.00

weld being that of the tube itself. The law demands new flues every three years; so they cannot be used longer, but it is known from the life of welds in fire boxes that the weld will last as long as the sheet; there are about two thousand locomotives running in the United States today with some part of the boiler welded, most of them with the flues welded in. Broken mud rings may easily be welded in place by cutting out a piece of the sheet at the break, welding the ring, and then welding the piece of plate back again.

Welding Machine Parts. The use of the electric arc for welding machine parts, new and broken, Figs. 83 and 84, is another field that offers great savings because of the delay incident to getting new parts as well as their cost, in cases of breakage, Fig. 85, and the great expense of making satisfactory mechanical joints in new work. Radical changes in design and details of construction are made possible by the use of this system in machine building and the fact that the parts can be so joined as to be literally one piece opens up great possibilities. For work on cast iron the graphite electrode is used and a cast-iron melt bar fused into place with the article in a horizontal position. Cast-steel parts requiring a moderate amount of welding may be done with the metallic electrode but large welds can usually be done to better advantage with the graphite electrode, using a wrought-steel melt bar or pieces of steel plate scrap to fill in with. Cast iron or steel can be welded soft enough to machine readily, by proper treatment, and the quality of the welded section can be made equal to the rest of the article. The effect of the electric arc on the composition of the metal is clearly indicated by Table III.

TABLE IV

Strength of Butt-Welded Joints

Plate Thickness Inches	Elastic Limit Lbs. Per Sq. In.	Tensile Strength Lbs. Per Sq. In.	Elongation % in 8 In.	Per Cent Efficiency
$\frac{1}{4}$	40930	54650	04.5	97.6
$\frac{3}{8}$	44930	53020	05.75	94.7
$\frac{1}{2}$	40160	51280	40.75	91.6

From Table III, it will be seen that it is necessary to use filling material of the proper composition if the weld is to be the same in composition as the original article. By merely using electrodes and melt bars with an excess of such elements as silicon, carbon, etc., this can be controlled to a very small variation from the desired amount. Unless the operator burns his metal by using too much current or applying it too long, there will be no appreciable

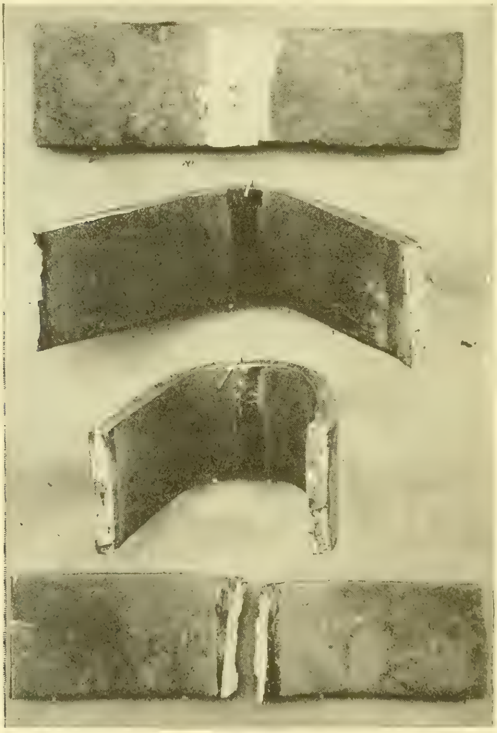


Fig. 86. Test Plates Showing Strength of Electric Welds
Courtesy of C & C Electric and Manufacturing Company

TABLE V

Relative Strength of Joints

Samples and Preparation	Breaking Strain Pounds	Length After Breaking Inches	Per Cent Efficiency
Original piece of plate	58,600	8.80	97.66
Lap joint, arc welded	54,800	8.94	91.33
Lap joint, riveted and welded	54,200	9.22	90.33
Butt joint, arc welded	47,800	8.28	79.66
Butt joint, acetylene welded	36,800	8.23	61.33
Lap Joint, riveted only	35,000	....	58.33

difference in color between the weld and the rest of the piece; so finished surfaces may be welded in many cases.

Strength of Weld. *Butt-Welded Joints.* The strength of the weld can be made the equal of the article welded by reinforcing, or it can be made very nearly equal by using filling material of high strength and welding flush with the surface of the piece, Fig. 86, this being especially true of steel plates. Some tests made by the author on steel plates of various thicknesses (with a nominal strength of 56,000 lbs. per square inch) showed the results given in Table IV.

The elongation in the filling material was less than in the original material, of course, owing to its being really a steel casting, but its ductility can be improved by hammering after welding and this is frequently done when welding heavy sections.

Comparative Test. In order to test the relative strengths of riveted, electric-arc-welded, and acetylene-welded joints, a set of steel samples were made up and tested as follows, each piece being $\frac{3}{8}$ inches by $2\frac{13}{32}$ inches in cross section and 8 inches long in the straight portion, Table V.

The steel plate used had a nominal strength of 60,000 pounds per square inch but was actually not up to standard, although it showed clearly the relative advantages of the various methods of making joints. Some tests recently made in England are shown in Table VI. Strength of welded piece was 88.43 per cent of original plate.

TABLE VI

Relative Strength of Original and Welded Plate

	Size of Sample Inches	Breaking Strain Pounds	Per Cent Elongation in 4 Inches	Per Cent Reduction of Area
Welded piece	.125×1.48	42,702	10.93	5.23
Original piece	.125×1.48	48,290	32.03	29.63

TABLE VII

Time and Cost of Welding

Article Welded	Time	Cost
Steel casting, shrinkage crack 6″ long by 1″ deep	8 min.	$00.04
Steel casting, riser 4″ by 4″ cut off	4 min.	.05
Forged steel locomotive frame, broken in 2 places	20 hrs.	18.28
12″ crack in back sheet of locomotive boiler	9 hrs.	5.47
Building up worn driving wheel instead of turning down	2 hrs.	.72
Welding 67 cracks in old fire box (saving over $1000)	2 wks.	52.60
Cast-steel tender frame, broken in 3 places	27 hrs.	19.00
Steel shaft, 2″ diameter, broken, welded ready to finish	1 hr.	.60
Broken railway type motor case, cast steel, welded	3 hrs.	1.95
Enlarged holes in brake levers, steel bars	4 min.	.05
Building up 2″ armature shafts, worn in journals	3 hrs.	1.80
Air brake piston rods, broken, welded ready to finish	30 min.	.35
Leaking axle boxes, cracks, welded in position	15 min.	.15

Cost of Arc Welding. The cost of arc welding will vary according to the nature of the work, the skill of the operator, and the cost of labor and current, but it is much less than for similar work done by any other process. It ranges from about three-fourths down to one-tenth that of the cost of acetylene welding, for various jobs, and the time required is much less. With the electric arc it is not necessary to keep a large portion of the work heated in order to prevent the chilling of the filling material, because the work forms the hottest (positive) terminal of the arc and a sufficient volume of heat is generated at the point which is being worked upon to insure perfect fusion.

Cost Data in Steam Railroad Shops. The figures in Table VII show the cost of several actual jobs done with arc welders, the labor being paid at the rate of 30 cents per hour and the current costing 2 cents per kilowatt hour, with the filling material figured at 8 cents per pound.

Comparison with Old Methods. The figures in Table VII will give a fair idea of the class of work and the costs of welding in steam railroad shops and car shops, and those in Table VIII will show the savings effected through the use of arc welding instead of making repairs by the old methods, of whatever kind.

Street Railway Repairs. Repairs to electric railway apparatus are also important in order to keep the rolling stock in useful service. The figures in Table IX, which give average costs for performing typical repair jobs in street car shops, are based upon the

TABLE VIII

Relative Costs of Repairs

Article Welded	Welding	Old Cost	Saving
Engine main frames, both broken.	$11.80	$56.20	$44.40
Driving wheel built up $\frac{3}{16}''$ on tread.	.72	8.00	7.28
General repairs on fire box side sheets.	66.51	342.62	276.11
Filling worn knuckle joint bushing hole.	.75	7.50	6.75
Welding 7 cracks in locomotive cylinder.	22.35	367.15	344.50
Broken mud ring on locomotive boiler.	32.07	118.06	85.99

relation between the cost of electric welding as opposed to replacement because that is usually the alternative.

One of the electric railway companies claimed that they repaired about 1600 articles a year which, if replaced by new pieces, would cost them nearly $15,000.00, and had also the benefit of the large amount of time saved by doing the work quickly and keeping their rolling stock in service a larger portion of the time. The use of electric-arc welding apparatus is not confined to the railway field, but equally interesting figures could be given as applying to work done in foundries, machine shops, boiler and tank shops, garages, and other places. These few will serve, however, to show the possible savings through using the arc for repair work in general.

In conclusion, it should be remembered that in order to weld with the arc it will require some practice in starting the arc, especially with the metallic electrode. The "trick" consists in touching the work and getting away as quickly as possible to the required distance, and yet not going so far as to rupture the arc. If the electrode is of metal, it will heat and stick to the work unless withdrawn quickly,

TABLE IX

Street Railway Repairs

Article Welded	Welding	New Part	Saving
Armature shaft, repaired in place.	$ 1.70	$ 4.72	$ 3.02
Armature shaft, large, repaired in place.	1.97	15.13	13.16
Railway motor axle cap, large.	.22	3.51	3.29
Railway motor armature bearing cap.	.27	6.07	5.80
Railway motor gear case, top half.	.48	7.30	6.82
Truck side frame, Brill 27-G.	.72	44.40	43.68
Truck side frame, Peckham 14-B.	.90	46.98	46.08
Brake head, building up worn socket.	.06	1.15	1.09
Motor frame, G. E. 90, railway type motor.	2.88	16.80	13.92

but it can easily be broken loose by a twisting motion of the hand. Care should also be exercised to see that the eyes and face are fully protected from the glare and heat of the arc, as it is hard on the eyes and affects the skin like bad sunburn. On the other hand, some men have done arc welding for years with no injury.

ELECTRIC-ARC CUTTING

Advantages of the Method. Cutting with the electric arc can be done very rapidly and economically and is done a great deal in foundries, scrap yards, Fig. 87, and other places. The slot cut is not so narrow as that cut by a gas flame, which is discussed later, but the metal is good after fusing out and may be used again. This is not always the case with metals cut by gas processes because there is a chemical action between the gases and the metals, whereas the arc is composed of the vapors of the metals worked upon and, aside from a slight oxidation when cutting iron or steel, there is no injurious change in the metals cut. Some of the more volatile elements may be reduced by the high temperature but the mass being cut will remain unchanged.

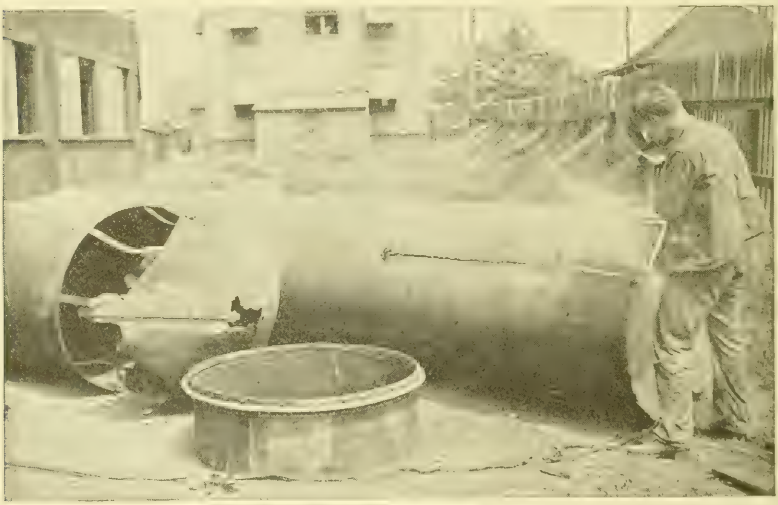


Fig. 87. Cutting Scrap with a Carbon Electrode
Courtesy of C & C Electric and Manufacturing Company

Current Requirements. Cutting is done with the graphite electrode and requires from 100 amperes on sheet metal up to several hundred on heavy castings and forgings. The maximum current which it is practical or necessary to use should never exceed 1000 amperes and the usual cutting operations take from 400 to 600 amperes. Direct current at 70 volts is used, the same as for welding, and almost any source of supply will give satisfactory results if proper means are provided for controlling the current. However, apparatus which has been specially developed for the service is much better and more reliable than makeshift devices and, as experience shows that the cost of cutting is just as important as the cost of welding, dead resistances should not be used.

Rate of Cutting. The rate of cutting has been found to be very close to one square inch of cross section per minute for each 100 amperes used in the arc. This rate will be increased slightly for sheet-metal work but applies very closely for heavy sections. On the basis given, a section 4 inch by 6 inch (24 square inches) can be cut in 4 minutes with 600 amperes, and experience shows this to be true. A steel plate 1 inch thick and 1 foot wide (12 square inches) can be cut in 2 minutes with 400 to 450 amperes; copper, aluminum, and other metals can be cut at about the same rates as steel sheet. When cutting it is necessary to make the slot wide enough to allow the arc to reach to the bottom of the cut instead of jumping to the sides and the piece should be placed so that the molten metal can run out of the slot. Work should begin at the top of the piece.

ELECTRIC BUTT AND SPOT WELDING

Characteristics and Development of the Process. The use of the electric current to heat metals to the welding point, by passing the current through the joint until the metal becomes plastic and then applying sufficient pressure to cause the pieces to adhere, was first proposed by Elihu Thomson in 1877; and the present day process of "resistance welding", in its various forms, is the result of his work. The process is based upon the phenomenon that a poor conductor of electric current will heat if current is forced through it, or that a good conductor will also heat if enough current is passed through it, and that the heating effect will be greater if alternating current is used than if direct current is used. Since an imperfect joint between two pieces of metal is a poor conductor and offers resistance to the passage of current, it will naturally heat and finally cause the metal to soften sufficiently to weld. In practice the operation is very rapid because comparatively large amounts of current are used and heavy pressures are applied.

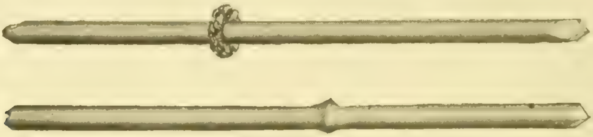


Fig. 88. Welded Bars Showing Upset
Courtesy of Toledo Electric Welder Company

Originally this process was used to weld bars and strips together, end to end, Fig. 88, performing the operation known as "butt welding", and this is today one of the principal uses of the system. Later a modification of the system was made in order that pieces of sheet steel could be welded; this resulted in the development of the operation known as "spot welding", by means of which lapped joints can

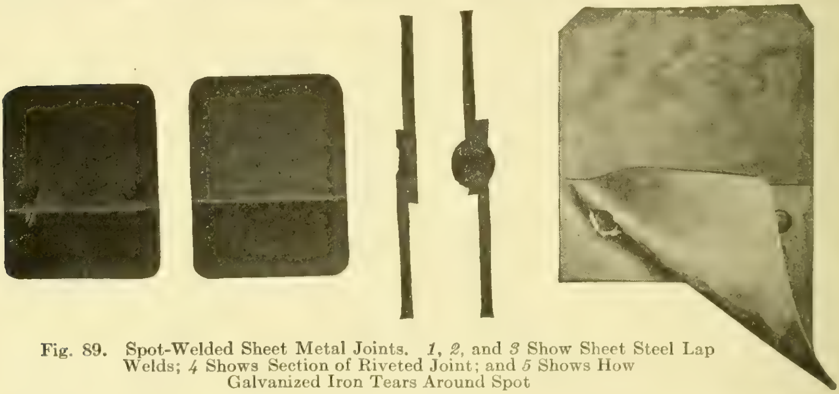


Fig. 89. Spot-Welded Sheet Metal Joints. *1*, *2*, and *3* Show Sheet Steel Lap Welds; *4* Shows Section of Riveted Joint; and *5* Shows How Galvanized Iron Tears Around Spot

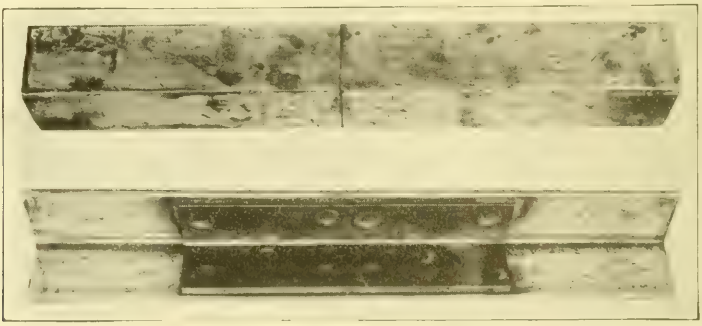
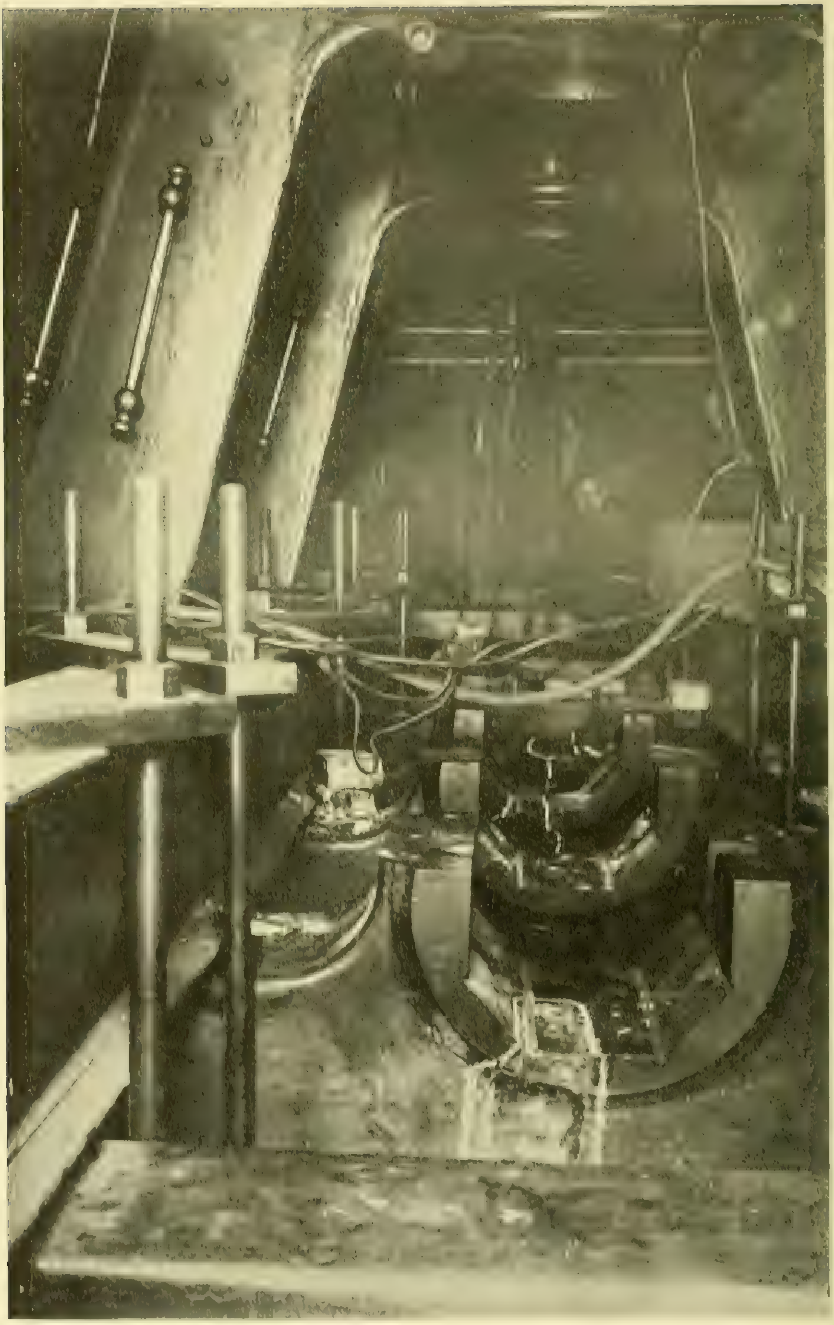


Fig. 90. Single Strap Butt Joint, Spot Welded
Courtesy of Toledo Electric Welder Company



ELECTRIC WELD MADE ON A 100-TON ICE MACHINE
Courtesy Electric Welding Company, New York

TABLE X

Metals, Alloys, and Combinations of Different Metals Actually Welded by the Thomson Process

METALS					
Wrought Iron	Wrought Copper	Tin	Cobalt	Aluminum	Gold (pure)
Cast Iron	Lead	Zinc	Nickel	Silver	Manganese
		Antimony	Bismuth	Platinum	
ALLOYS					
Various Tool Steel	Mushet Steel	Wrought Brass	Fuse Metal	Aluminum and Iron	Silicon Bronze
Various Mild Steel	Stub Steel	Gun Metal	Type Metal	Aluminum Brass	Coin Silver
Cast Steel	Crescent Steel	Brass Composition	Solder	Aluminum Bronze	Gold Alloy
Chrome Steel	Bessemer Steel	Nickel Steel	German Silver	Phosphor Bronze	
COMBINATIONS					
Copper to Brass	Brass to Wrought Iron	Brass to Tin	Wrought Iron to Tool Steel	Wrought Iron to Mushet St.	Wrought Iron to Nickel
Copper to German Silver	Tin to Zinc	Brass to Mild Steel	Gold to German Silver	Wrought Iron to Stub Steel	Tin to Lead
Copper to Gold	Tin to Brass	Wrought Iron to Cast Steel	Gold to Silver	Wrought Iron to Crescent St.	Mild Steel to Tool Steel
Copper to Silver	Brass to German Silver	Wrought Iron to Mild Steel	Gold to Platinum	Wrought Iron to Cast Brass	Nickel Steel to Machine Steel
	Brass to Platinum	Steel to Platinum	Silver to Platinum	Wrought Iron to German Silver	

be made, Fig. 89, particularly for thin material. Heavy plates cannot be spot welded so readily as thin ones but they are frequently welded edge to edge, forming a butt weld, or a combination butt and

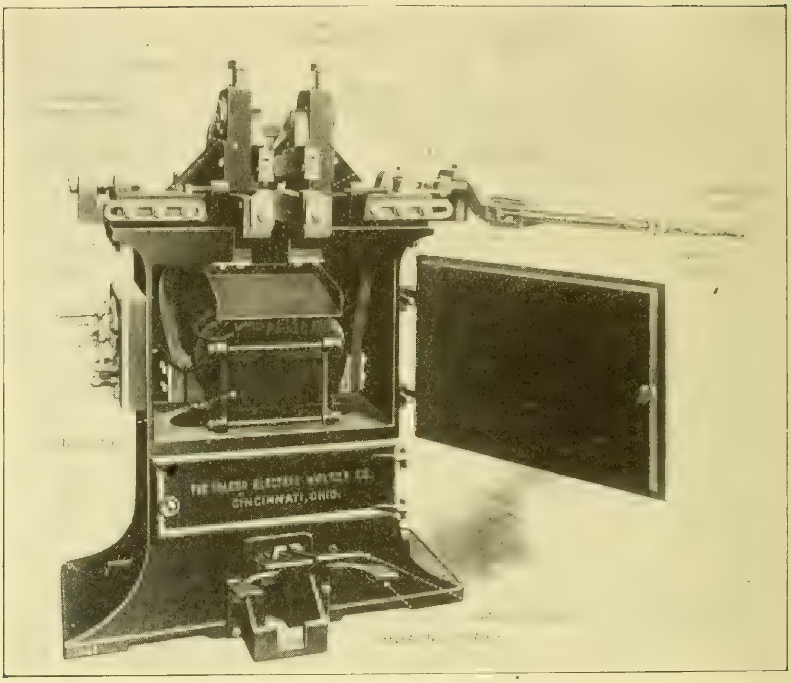


Fig. 91. Double Treadle Butt Welder
Courtesy of Toledo Electric Welder Company

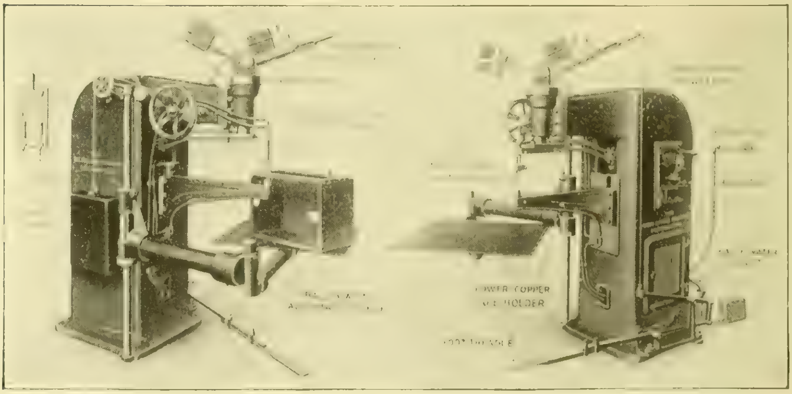


Fig. 92. Principal Parts of Spot Welder
Courtesy of Toledo Electric Welder Company

lap weld, as in Fig. 90. Special machines have been developed by the various manufacturers for numerous operations and for a wide range of articles, a few of which are shown in subsequent illustrations, and the work done with them is of the highest class. Practically every kind of metal can be welded by this process and many different kinds may be joined to each other, as shown in Table X. The great advantage of this process lies in the amount of work which can be done in a short time, but it is limited almost exclusively to the production of new articles instead of being also good for repair work like the arc system.

From a study of Table X it will be seen that practically all of the commercial combinations of metals can be made with butt or spot welding apparatus and, it may be added, there is no other system in use today that will do welding on as wide a range of metals, alloys, or combinations. This system operates on a very low voltage—about 3 volts—and the important factor, as with arc welding, is the amount of current.

Equipment Required. Butt or spot welding requires practically a separate machine for each class of work to be done, these machines consisting of a main frame, Figs. 91 and 92, containing a transformer and some means for clamping the article to be welded, together with a device for applying the pressure required to force the parts together when heated. Unless the machine is designed for one special sort of articles, it is necessary to have a reactive coil to adjust the current to suit the work and a switch to control this coil. As with any other electrical device, a main switch for connecting the welder to the power circuit is necessary, of course, and the larger sizes of machines are water cooled.

The illustrations scattered through the text of this section show the more important types of machines, and the pipes for carrying the cooling water to the copper contacts are clearly shown on most of them. These machines are built for welding pieces with cross sections as small as fine wires, Fig. 93, and as large as 7 or 8 square inches in section and may require as much as 200 horsepower for large work. Butt- or spot-welding machines can be operated from any single-phase power circuit supplying current at a constant voltage by providing the proper transformer, but direct current cannot be used.

Butt welders are comparatively low machines, Fig. 94, and have the clamps for the work on top, generally in the form of jaws with a lever for operating each pair, Fig. 95, and another lever or a hydraulic cylinder to bring the pieces together and to apply the required pressure when properly heated. The current is carried into the pieces through the jaws and is usually turned on auto-

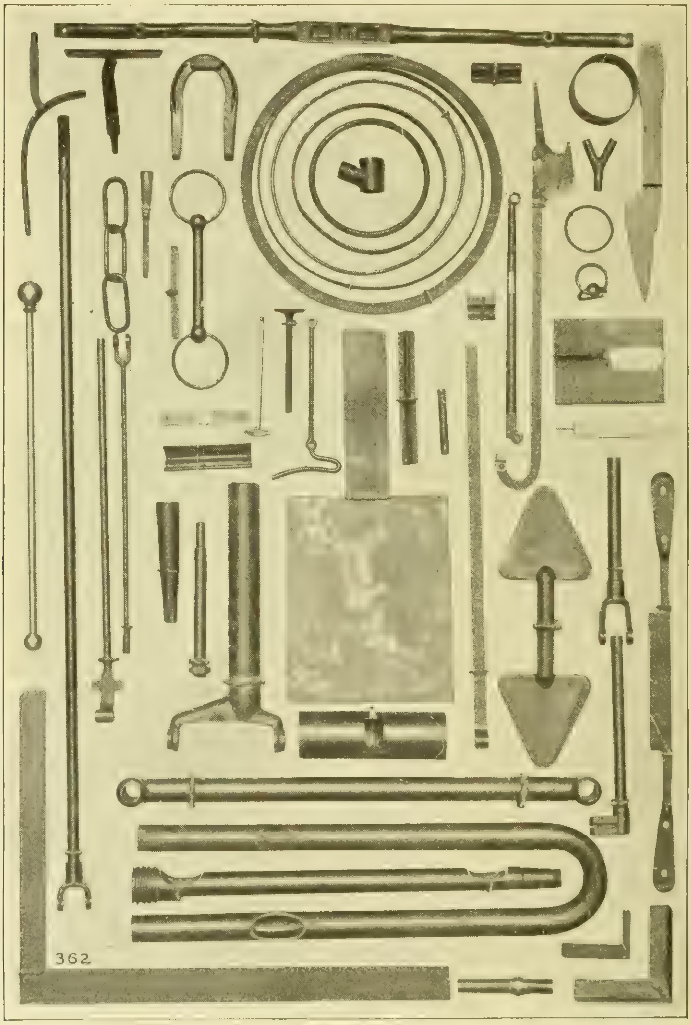


Fig. 93. Samples of Butt Welding
Courtesy of Toledo Electric Welder Company

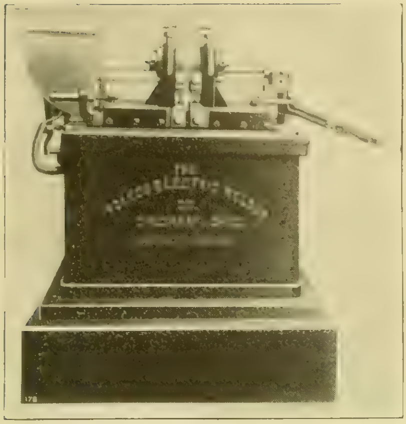


Fig. 94. Toledo Small Butt Welder

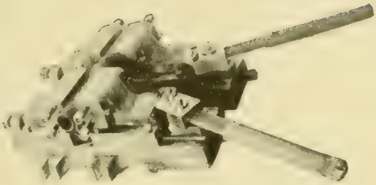


Fig. 95. Butt Welder Clamps for Pipes
Courtesy of Thomson Electric Welding Company

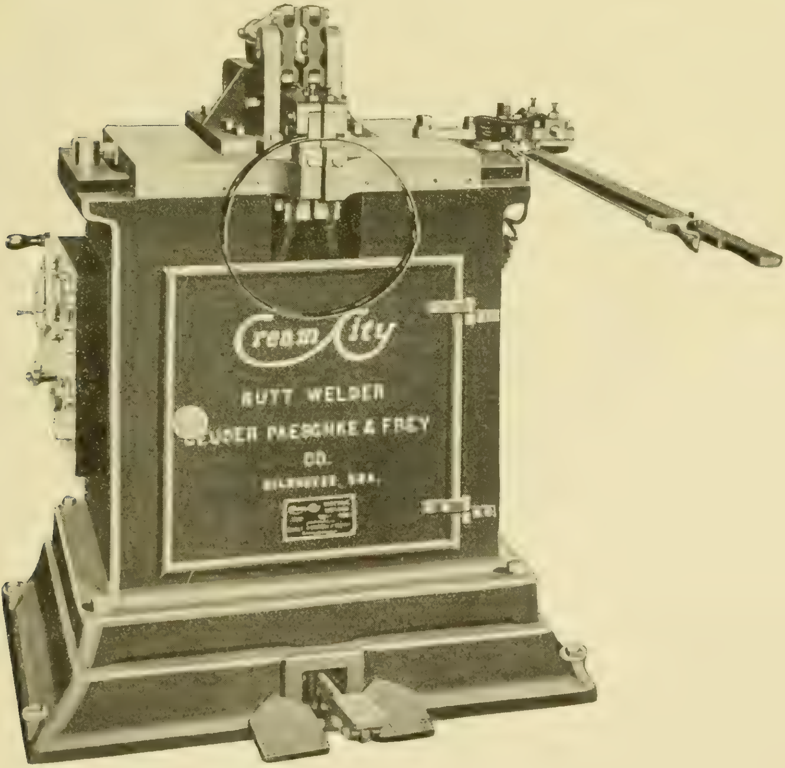


Fig. 96. Foot-Operated Butt Welder
Courtesy of Geuder, Paeschke, and Frey Company

matically after the parts are clamped into position. Foot levers are also provided on some forms of machines, Fig. 96, for clamping in order to leave the workman's hands free to handle the work. Spot welders, Figs. 97 and 98, are usually higher but smaller and have a pair of arms, Fig. 99, extending to one side for carrying the two welding tips or contacts; the pieces are laid together and placed on the lower contact and the upper one is forced down against it. The current is automatically switched on, when the contacts close, and the pressure is applied by a hand or a foot lever. Special machines are also made for rail welding, etc. (See Figs. 104 and 107.)

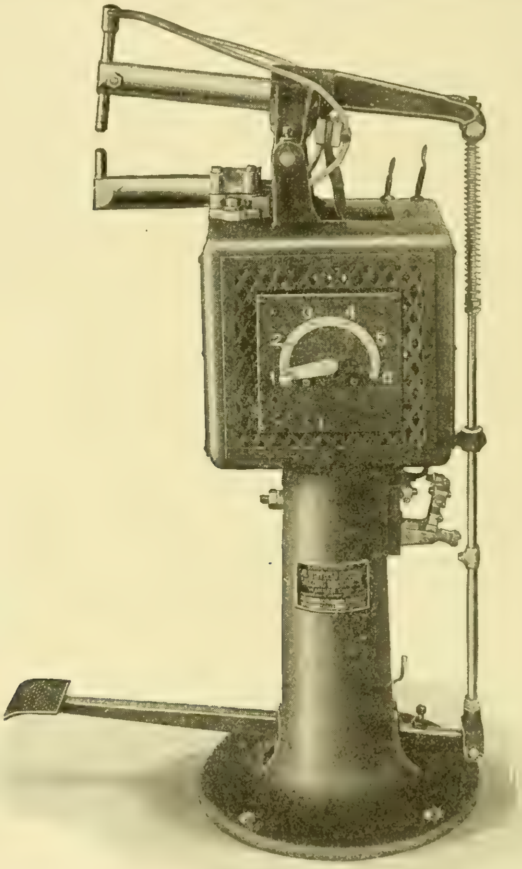


Fig. 97. Foot-Operated Spot Welder for Sheet Metal
Courtesy of Winfield Electric Welding Machine Company

Source of Power. *A. C. City Circuits with Transformer.* The source of power for butt and spot welders should have the same general characteristics as for arc welding; that is, they should deliver the current at constant voltage regardless of load. In most places current can be purchased from a public service corporation and a transformer, to give current at the desired voltage, will be furnished to power users. City distribution circuits are usually operated at 2200 volts in order to reduce the amount of copper required for the lines and, since alternating current is required for butt and spot welding, it is easy to get current at proper voltage by using a

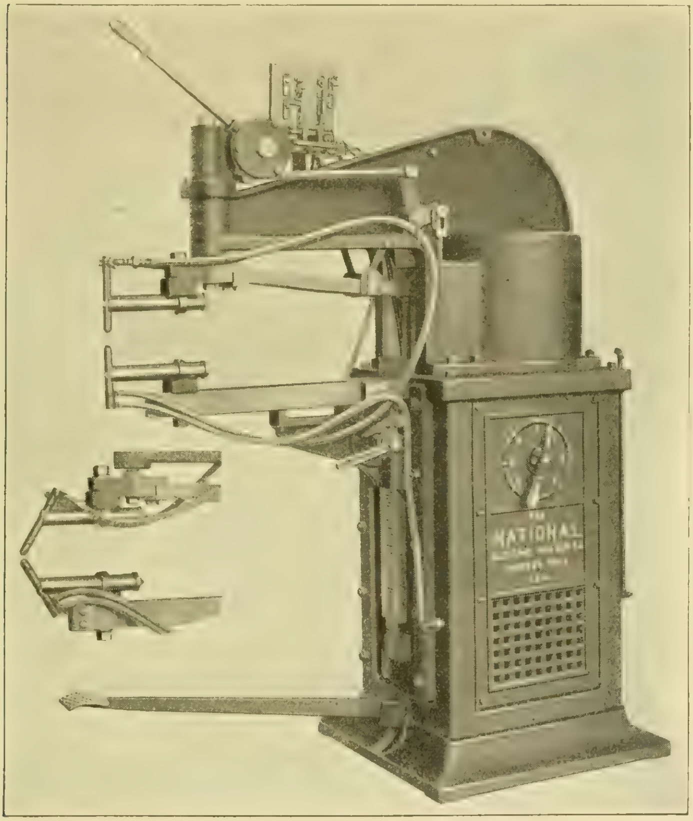


Fig. 98. 24-Inch Drop Arm Spot Welder Showing Different Positions of Universal Points
Courtesy of National Electric Welder Company

transformer. Most welders are provided with their own transformers wound to operate on a 220-volt circuit, although they can be made for use on any voltage up to 550 if necessary. Consequently, the line transformer should have a 220-volt secondary winding. The welding transformer will step the voltage down to the proper amount for welding and at the same time increase the current to the required amount. When it is necessary for the user of a welder to furnish his own power, it is best to use a motor-generator set, as such a machine will give better regulation than a rotary converter or a synchronous transformer. Engine-driven alternating-current generators may be used, if adequate means are provided to maintain constant speed under all conditions of load, and this is important for spot welders especially, because of the rapid and wide fluctuations of load in service.

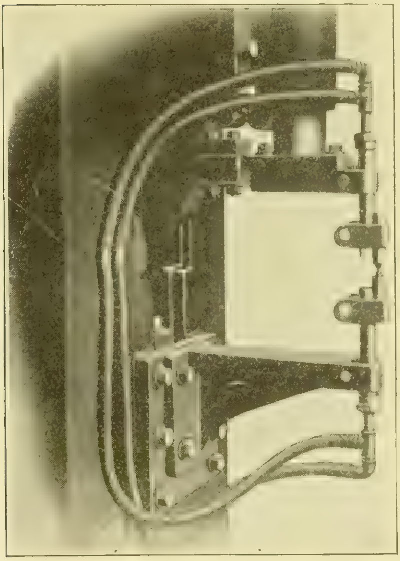


Fig. 99. Details of Spot Welder
Courtesy of Toledo Electric Welder Company

Transformer Requirements. The transformer does its work through magnetic action and entirely without moving parts. It consists of a laminated iron core, or body, with two sets of copper coils or windings so arranged that the alternating current in the line, or primary side, coils magnetises the iron core and sets up a magnetic field which causes current to flow in the welding, or secondary side, coils. The wires and number of turns in the two sets of coils are so proportioned that the secondary coils produce a high current at low voltage, when the primary coils are energized by a low current at high voltage. For most welding operations the voltage is from 3 to 5 volts, and the power required will vary from about 1 horsepower for small work up to 200 horsepower for large work. The power will vary inversely as the time required to make the weld, rapid work demanding more power than slow work.

PROCESSES OF WELDING BY RESISTANCE METHOD

Classification. The process of welding by the resistance method is the simplest of all methods of joining metals, and is also the quickest and cheapest method for work which may be easily handled. While it is true that it is limited almost exclusively to new work and to articles of moderate and small size, it is possible to do work in such quantity and of such variety that this system is used in numerous lines of production. The operation consists mainly in clamping the pieces in the machine, passing the current through the point of contact until it heats, and then squeezing the pieces together until they join. At the proper temperature, the metal will be in a plastic state and the molecules of the two pieces will amalgamate, or mix, so as to unite and form one piece. If the pieces are of different metals, the result will be an alloy of the two metals at the joint. When the nature of the metal is such that it is injured at high temperatures—as, for instance, brass or tool steel—it should be heated quickly and pushed together hard enough to squeeze the burnt metal out of the weld. Experience will soon show the correct heat for the best results on each metal, but the makers of the various welders will be glad to state the proper current, time, and temperature for any sort of work.

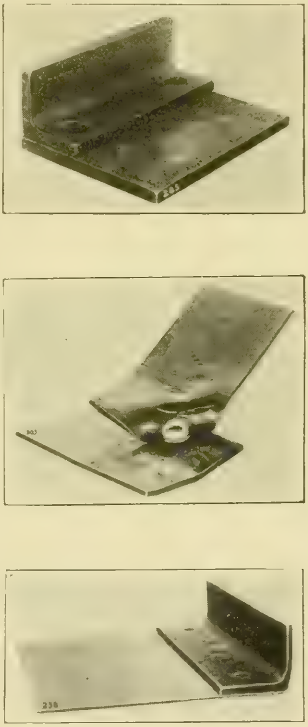


Fig. 100. Examples of Spot-Welded Joints
Courtesy of Toledo Electric Welder Company

Butt welding, as its name indicates, is the operation of welding two pieces of metal end to end or side to side, and spot welding is the operation of welding two pieces by lapping them and welding them in spots only, Fig. 100, instead of full width as with butt welding. Numerous modifications of both these processes have been developed for special shapes and sizes of pieces, among which may be mentioned lap welding, tee welding, cross welding, seam welding, upsetting, jump welding, annealing, and brazing. The two latter applications of resistance-welding machines are not welding in the true sense but are practical applications of the apparatus, which should be understood. Hardening and tempering may also be done through the use of this apparatus and rivet heads, heated ready for shaping, can easily be formed by pressure. Light or small work can be done on large machines, of course, but not very economically, and large work can be done on small machines but it is a dangerous practice on account of the excessive current required and should be discouraged.

Butt Welding. Butt welding is applicable to welding metals of practically the same cross section by bringing them together end to end or edge to edge; all of the energy passing through the joint is effective because it is confined to a limited area of contact. A slight projection or fin will be raised at the joint, Fig. 88, due to the flowing of the soft metal, but this is easily removed.

Spot Welding. Spot welding is the operation of joining sheets by heating and softening the metal in spots only, each about the size of a rivet, and applying pressure while the metal is plastic. The operation causes a slight thinning of the metal at the weld, No. 3, Fig. 89, due to the pressure, but when it is properly done the joint should be as strong as the rest of the sheet.

Lap Welding. Lap welding consists in making a joint by overlapping the edges of the sheets to be welded, heating the joint, and applying pressure by means of rolls which pass along the seam. This makes a continuous seam, instead of merely a series of spots, and gives a tighter and stronger joint than spot welding. It is used to a lesser degree than either of the other methods, but is coming into more general use for special purposes such as welding-in barrel heads, making grease cans, oil tanks, etc. Seam welding is a similar operation.

Butt Seam Welding. Butt seam welding is an operation similar to ordinary butt welding in one respect and like lap welding in another. It is used for making the seam in steel plate articles of moderate thicknesses, such as range boilers; it is done in a machine which brings the edges of the plates together and does the welding by pressure while hot, in the usual manner, Fig. 101. The special feature of the machine lies in the fact that the current is carried into the plates and across the seam by means of rolls each side of the joint. As the work progresses through the machine, the rolls keep the current always passing across the joint just ahead of where the pressure is applied.

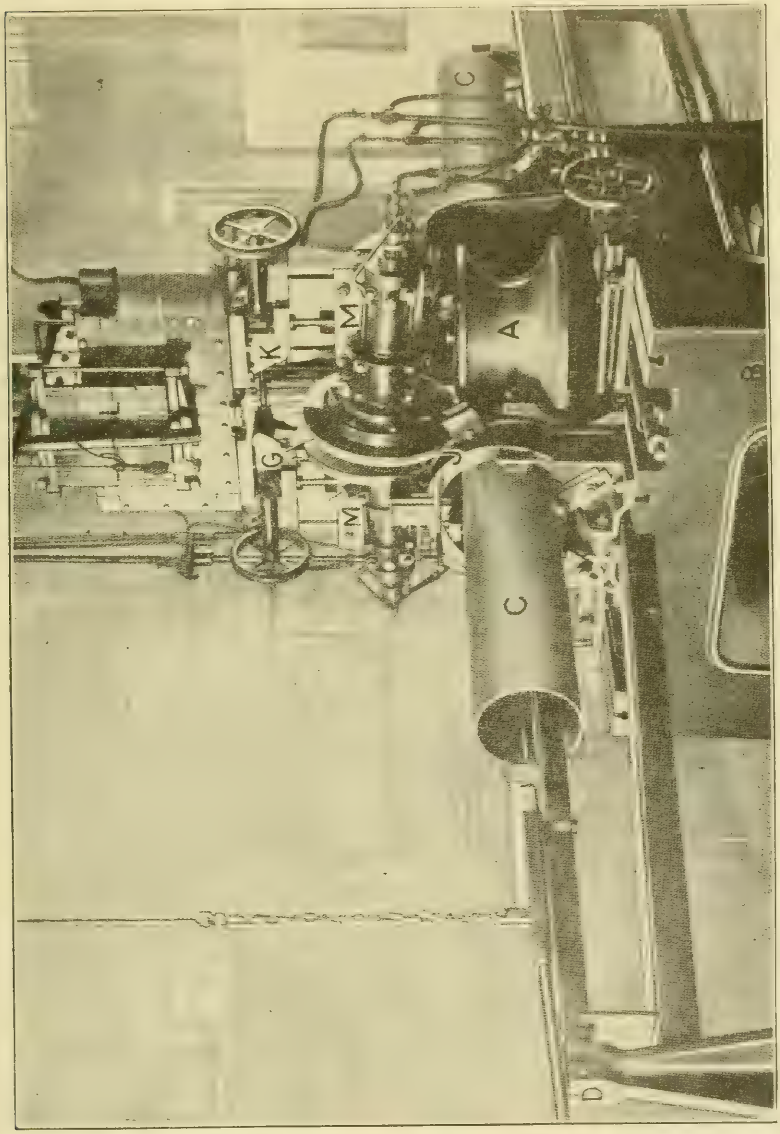


Fig. 101. Electric Welding Machine for Tubes with Tube in Position

Tee Welding. Tee welding is the process of making a weld in the shape of a "T" by welding one piece to the side of another. The peculiar feature of this process is that the head of the tee must be heated first in order that the shank may not be burned before the parts are both soft enough to weld.

Jump Welding. Jump welding is similar to tee welding and is used on light stock which does not require preheating before welding. This process is also used for pipe work, when forming tees or welding branches into larger pipes, and the hole in the header or main pipe should be made before welding the branch.

Cross Welding. Cross welding is done when forming wires or bars into screens or when making any other article requiring the crossing of strips. The pieces are merely laid together and a welded joint formed at the crossing in either a butt-or a spot-welding machine. The pieces will flatten at the joint, of course.

Upsetting. Upsetting is the operation of forming an enlarged section on a bar for the purpose of increasing its strength or for reforming it to another shape. The bar is placed between the jaws of a butt welder, the current passed through the space to be upset, and pressure applied when the bar heats. The pressure will squeeze the metal up so that the bar will expand, after which it may be hammered into the desired shape while hot. This process must be distinguished from ordinary butt welding in which the joint swells and shows an "upset". Deliberate "upsetting" is usually carried much further. A "flash weld" is a similar operation and is used on wide stock or on rectangular pieces and when ever the ends of the stock cannot be trimmed square. It consists in squeezing the metal so hard and rapidly while soft that it almost "squirts" apart and forms feathery fins around the joint which must be ground off. It is used when welding brass and copper and an amount equal to the diameter or thickness of the material is taken up in the weld.

Electric Annealing. Electric annealing can be done with either a butt welder or a spot welder and consists in passing the current through the part to be annealed, heating it until soft, and allowing it to cool slowly. Hardened steel plates, springs, dies, tools, chilled rolls, etc., may be treated this way and may then be drilled or cut very readily. When much of this work is to be done, it is better to have a special machine made for the article because it will reduce the cost.

Hardening and Tempering. Hardening and tempering can also be done by heating the pieces in a butt welding machine and, when the desired color is reached, chilling in the usual manner. The advantage in this process lies in the fact that the work is always in sight.

Electric Brazing. Electric brazing can be done quickly by placing the parts in a butt- or seam-welding machine, heating the joint, and then applying the spelter and flux, allowing them to run into the joint. The temperature can be controlled more easily than by any other process and the work is always in sight. It would seem, however, that welding would be preferable to brazing.

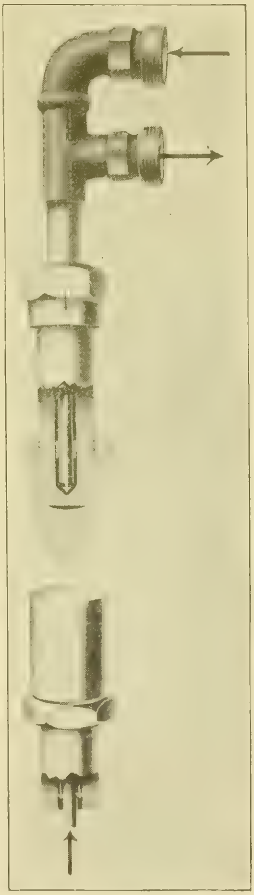


Fig. 102. Water-Cooled Die Point
Courtesy of Toledo Electric Welder Company

Electric Riveting. Electric riveting is another recent variation of the spot-welding process and consists in making the holes in the pieces, inserting the rivets, heating them between the tips of a spot welder, and then pressing them to form heads while soft. It is very quickly done and eliminates the rivet heating furnace; for heavy work it is good, but is more expensive than straight spot welding for thin plates.

General Matters of Good Practice. *Freedom from Dirt and Grease.* When doing either butt or spot welding or any of their variations, it is important to see that the surfaces are cleaned thoroughly before starting to weld them because the presence of grease, dirt, or other matter between the surfaces will prevent a perfect joint. The cleaner and better the stock the easier it is to weld, the less current it takes, and the less wear on the dies. Dirt, grease, and scale are insulators, in most cases, and it takes only a small amount, at the low voltage used, to prevent the flow of current; if there is any undue heating in any part of the machine where there, is a joint in the circuit, it should be carefully examined for dirt and grease and then cleaned. Bolts frequently work loose and, allowing oil to carry dirt under their heads, cause heating. There is no danger of a shock from the welding circuit because of the low voltage but

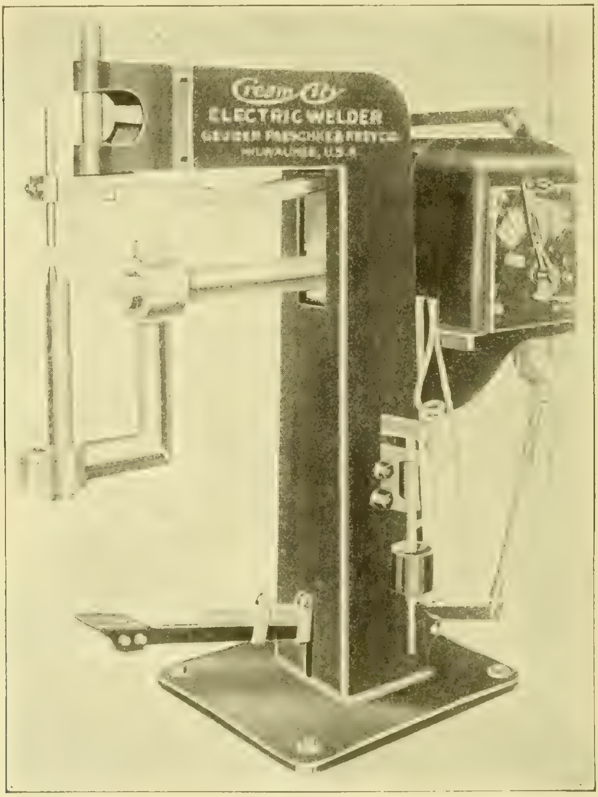


Fig. 103. Spot Welder Showing Simple Construction
Courtesy of Geuder, Paeschke and Frey Company

the line, or primary side of the machine, should be avoided, if possible or handled with proper precaution.

Avoiding Heating of Parts. If the machine has been properly installed, there should be no trouble so long as the cooling water flows through the welding dies, Fig. 102, and everything is kept clean and all connections tight. The only moving parts on most contact welders are the clamps and jaws, Fig. 103, and these are easily watched; the transformer is so simple it should never get out of order except in cases of accident. The switches should be enclosed to prevent accidental contact and ordinarily are automatic and out of reach.

APPLICATIONS TO MANUFACTURE

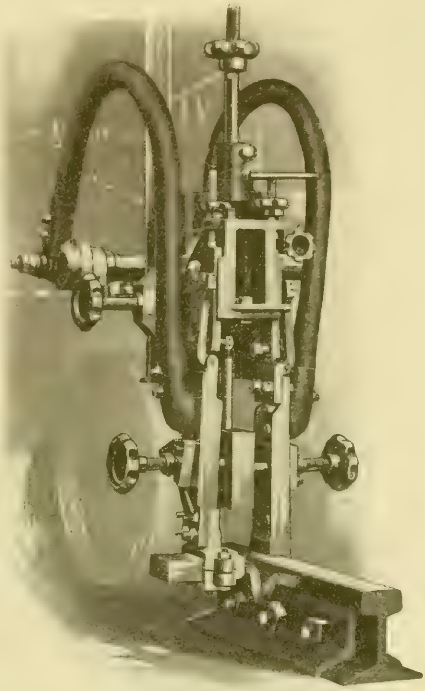


Fig. 104. Spot Welder for Bonding Rails
Courtesy of Electric Railway Improvement Company

General Applications. The applications of welding by this process are too numerous to mention here, but some of the more important ones are in the manufacture of wagon tires, axles, iron wheels, bicycle parts, pedals, brake parts, chain adjusters, tools, shovels, printers rolls, wire and strip hoops, screens, special piping, rail bonding, as shown in Figs. 104 and 105, rings and chains, automobile parts, steering knuckles and rods, step brackets, valve heads and stems, typewriter bars, sheaves and pulleys, umbrella rods, frames, Fig. 106, structural iron work, stovepipe, knives, steel enamelled ware, etc. Practically every kind of metal can be welded and every shape or section that can be put into the machine can be manipulated if the surfaces can be brought together. Special machines for welding the joints in track rails have been devised and Fig. 107 shows the cars and other details of the equipment required.

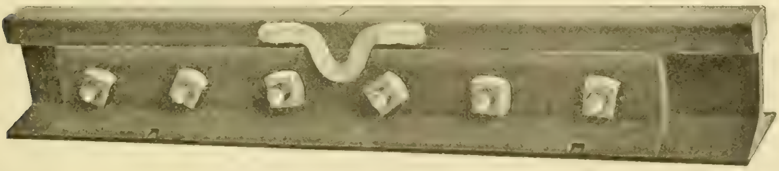


Fig. 105. Bonded Rail
Courtesy of Electric Railway Improvement Company

A large spot welder, the details of which are shown in Fig. 108, is used and is made so that the jaws hang vertically down from a crane, with a transformer suspended between them. Pressure is applied through a hydraulic cylinder and plates are welded to each side of the web of the rail. The top of the rails is ground smooth after welding.

When welding hoops, Fig. 96, the strip is bent around and the ends brought together and clamped in the jaws of a butt welder. Most of the current will cross the joint, because the jaws are set close and the path across the joint offers the least resistance, although a part of the current will go around the hoop. Chains are welded in the same manner, Fig. 109, and the work is successful in spite of the short length of circuit around the link. Automatic machines are

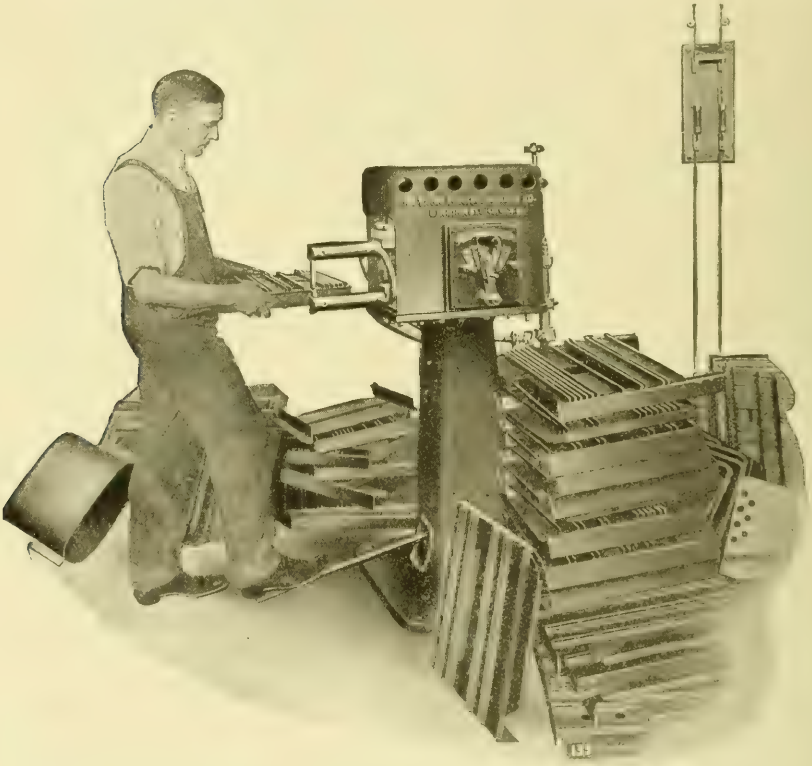


Fig. 106. Spot Welder for Pressed Metal Frames
Courtesy of Toledo Electric Welder Company

sometimes used for chain making, wire fencing, screens, and other articles requiring a repetition of numerous simple joints, Fig. 110. Sheet steel and aluminum automobile bodies, mud guards, bonnets, and other parts are spot welded. Coffeepots, Fig. 111, kettles, and similar articles have their spouts and handles spot welded on, and coal pails, wheelbarrow bodies, spiral piping, coal chutes, boxes, cabinets, lockers, steel shelving, and hundreds of other articles offer almost unlimited opportunities for welding by this system. Butt welding is used to almost as great an extent as blacksmith welding and is much cheaper.

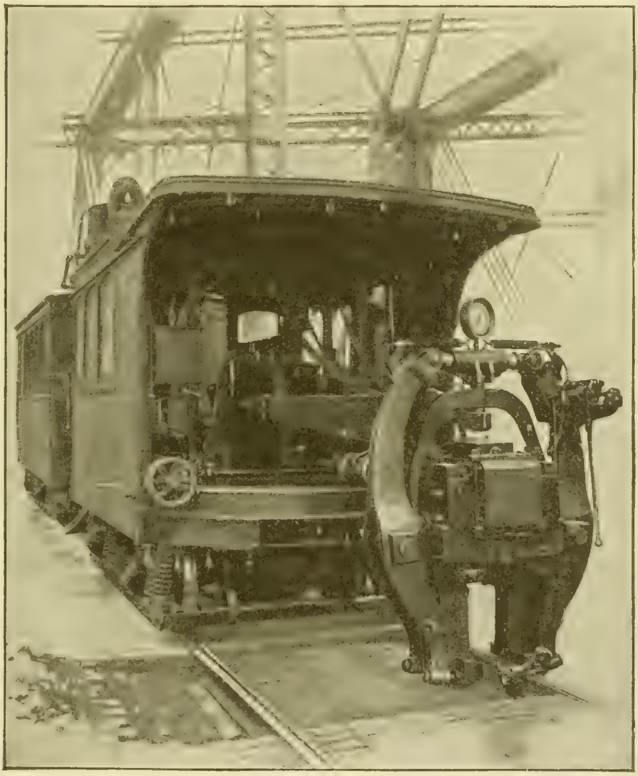


Fig. 107. Electric Rail Welder and Car
Courtesy of Lorain Steel Company, Johnstown, Pennsylvania

Practice with Different Metals. *Iron and Steel.* Iron and steel are used more than any other metals and are, therefore, the metals most commonly welded by all processes; fortunately they are about the easiest to weld. For butt-welding iron or steel the stock should be clamped in the dies with comparatively little projection and the ends brought together before switching on the current. Considerable pressure is required because it is better to keep the temperature below the melting point. For an upset weld the dies should be about 1 inch apart and for a flash weld they should be about $\frac{1}{4}$ inch apart for ordinary sections.

Cast Iron. Cast iron cannot be welded commercially by this process because of its crystalline structure and the high percentages of carbon and silicon in its composition. The arc-welding process is the one to use for cast iron, as the metal passes readily from the crystalline to the fluid state when sufficiently heated, which is a disadvantage for butt or spot welding.

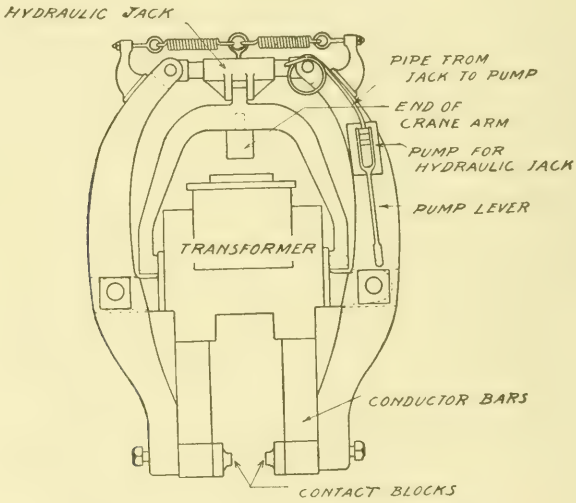


Fig. 108. Diagram of Lorain Rail Welder

High Carbon Steel. High carbon steel can be welded by this process but must be annealed afterwards to relieve the stresses set up by the localized heating. A good joint can always be made with steel of .25 per cent carbon or less, frequently with steel containing up to .75 per cent carbon, but seldom with that containing more than .75 per cent. It requires an experienced operator to get good results with high carbon steel because it is so easily injured. High and low carbon steels can be welded together successfully by good operators, if the low carbon stock is allowed to project further through its die than the high carbon steel.

Nickel Steel. Nickel steel may be welded readily and the strength is high.

Copper and Brass. Copper and brass may be welded and have the joint strong enough to stand the strain of redrawing through dies but the pressure, when welding, must be less than for iron.

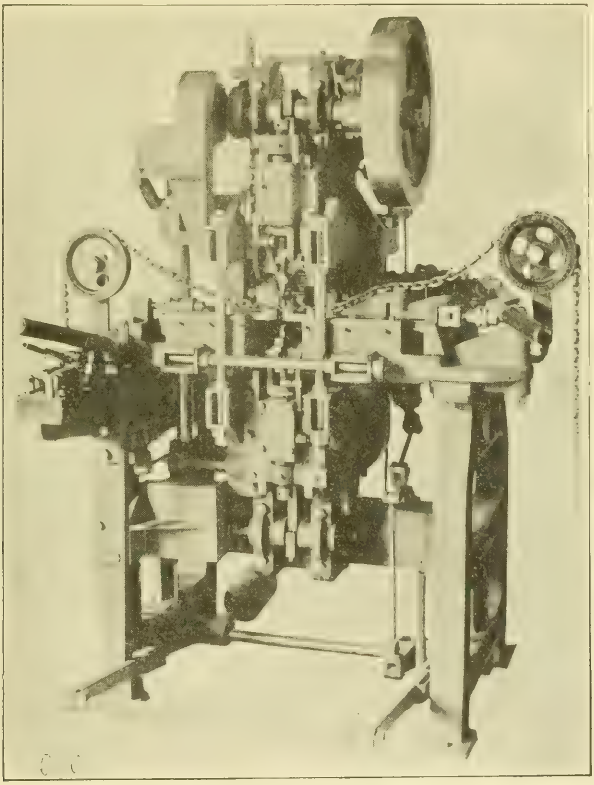


Fig. 109. Semi-Automatic Chain Welder
Courtesy of Thomson Electric Welding Company

The metal is really allowed to fuse, or melt, at the joint and the pressure should be just sufficient to force out the burnt metal. It is because of this that good welds are possible, but the current must be shut off as soon as the ends of the pieces soften, and an automatic switch is provided for this on some machines. The dies should be set apart 3 or 4 times the thickness of the stock and more current should be used than for iron.

Iron and Copper. Iron and copper can be welded together, if the section of the copper is less than the iron at the point of contact, as the former is a better conductor.

Galvanized Iron. Galvanized iron of No. 22 gage and heavier can be spot-welded but it will burn the zinc off at the welded spot and on both sides of the sheets. For thinner sheets it does not pay to try welding by this method.

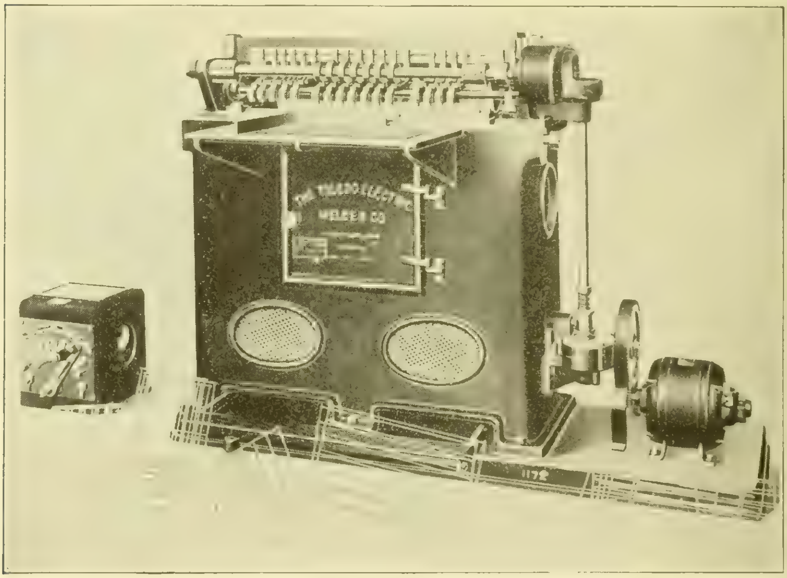


Fig. 110. Electric Welder Capable of Welding Sixteen Wires at One Time
Courtesy of Toledo Electric Welder Company

Sheet Brass. Sheet brass can be welded to brass or to sheet steel after sufficient experimenting to determine the proper heat and pressure.

Sheet Aluminum. Sheet aluminum of some grades can be spot-welded but the surface will be rough and pitted where the die points touch it.

Sheet Copper. Sheet copper is hard to weld because of its low resistance, but it can be done by an experienced operator using sufficient current.

TABLE XI

Power and Time for Butt Welding

IRON AND STEEL				BRASS				COPPER			
Area Sq. In.	Power Kw.	Seconds	H. P.	Area Sq. In.	Power Kw.	Seconds	H. P.	Area Sq. In.	Power Kw.	Seconds	H. P.
.25	6.	20	8.	.125	6.	10	8.	.0625	5.	5	7.
.50	10.	28	13.5	.25	12.	14	15.7	.125	8.5	7	11.5
.75	13.	35	17.5	.375	12.6	17	17.	.1875	12.	9	16.
1.00	18.75	40	25.	.50	15.	20	20.	.250	18.	10	24.0
1.50	29.5	44	39.5	.75	25.	22	33.5	.375	28.5	11	38.
2.00	33.	57	44.0	1.00	29.5	28	39.5	.500	32.	14	43.
2.50	38.	63	50.	1.25	37.	32	50.	.625	37.	16	50.
3.00	43.5	70	58.5	1.50	43.	35	52.7	.75	43.	18	52.
4.00	56.3	80	76.	2.00	53.	40	71.	1.00	55.5	20	75.
5.00	61.7	90	83.	2.50	60.	45	80.	1.25	61.	23	82.
6.00	69.	98	92.5	3.00	66.	49	88.5	1.50	68.	25	91.

Limits as to Thickness of Metal. There is a limit to the thickness of sheets which can be spot-welded and to the sectional area of pieces which can be butt-welded because of the heating of the dies or clamps by the large amounts of current required for heavy work. If enough cooling water is passed through the dies to prevent overheating, it will also carry off some of the heat from the work and a point is soon reached where the area of contact of the dies becomes so great as to be a disadvantage. Theoretically, it is possible to weld any size section with a comparatively small current by leaving it on long enough, but in practice we must take radiation into account, for a point is soon reached where radiation equals the heating effect of the current and, at this point, the temperature remains constant.

Fig. 111. Coffee Pot with Spot-Welded Spout

Power Required. The power required for butt and spot welding is easily determined from the cross section and material of the piece, because considerable experimental data is available. As previously stated, the power required for this kind of welding varies inversely as the time consumed in making the weld. This means that the longer you can take to do the work, the less current you will require; and the quicker you wish to accomplish the work, the more

TABLE XII

Butt Welder Data

Rd. Iron Diameter in inches	Area in Square Inches	Kw. Required	H. P. at Dynamo	Time in Seconds to Make Weld	Cost per 1000 Welds at 1 cent per Kw.
$\frac{1}{4}$	.05	2	3	3	0.02
$\frac{3}{8}$	.11	3.5	5	5	.05
$\frac{1}{2}$	.20	5	7.5	5	.07
$\frac{5}{8}$	.31	7.5	12	10	.21
$\frac{3}{4}$	.44	12	17	15	.50
$\frac{7}{8}$	.60	15	22	18	.75
1	.79	18	25	20	1.00
$1\frac{1}{8}$	.99	25	35	25	1.73
$1\frac{1}{4}$	1.23	35	50	30	2.90
$1\frac{1}{2}$	1.77	50	70	40	5.55
$1\frac{3}{4}$	2.41	65	85	45	8.12
2	3.14	75	100	50	10.42

As the rate charged for current varies in different places, we have figured the current at one cent per Kw. hour to give a basis for calculating the cost. Multiply the prices given above by the rate per Kw. hour charged by your local electric light company, and that will give your cost for current for 1000 welds.

current you must use. The total amount of energy in kilowatt hours will be the same in either case, but a larger transformer must be used for rapid work.

Tables XI, XII, and XIII will give a good idea of the power and time required for various thicknesses of metal with butt welding and spot welding, and it will be well to compare the effect of time on the current used.

Table XII is different from Table XI for similar sizes of section because of the difference in the time taken per weld.

Table XII is based only on the use of iron rods, the diameters being given in Column 1. Table XIII is based upon steel, but in the form of sheets. The costs of making the welds as given in Tables XII and XIII are very interesting and should be carefully noted.

Cost of Butt and Spot Welding. The cost of welding by both butt and spot methods can easily be figured from tables XII and XIII by determining the cost of current for the operating conditions under consideration and adding the required amount for labor and overhead charges in the shops. The latter item is very important and will have a noticeable influence on the cost of welding in most shops. The labor for handling the material to and from the

TABLE XIII

Spot Welder Data

Gages of Sheet Steel	Thickness in Fractions of an Inch	Thickness in Decimal Parts of an Inch	Approximate Kw. Capacity	H. P. at Dymano	Time in Seconds to Make a Weld	Cost per 1000 Welds at 1 Cent per Kw.
28	1–64	.015625	5	8	.3	.0045
26	3–160	.01875	6	9	.4	.0065
24	1–40	.025	7	11	.5	.01
22	1–32	.03125	8	13	.6	.0135
20	3–80	.0375	9	14	.7	.0175
18	1–20	.05	10	15	.8	.0225
16	1–16	.0625	12	18	.9	.030
14	5–64	.078125	14	20	1.	.039
12	7–64	.109375	16	23	1.3	.058
10	9–64	.140625	18	25	1.5	.075
9	5–32	.15625	20	30	2.	.112
8	11–64	.17187	23	34	2.5	.16
7	3–16	.1875	25	37	3.	.21
6	13–64	.20312	28	42	4.	.31
5	7–32	.21875	30	45	5.	.42
4	15–64	.23437	33	48	6.	.55
3	1–4	.25	35	53	7.	.68

Based on using fairly clean stock, this table will give an idea of the time and current required in welding different gages of sheet steel.

As the rate charged for current varies in different places, the current has been figured at one cent per kw. hour to give a basis for calculating the cost. Multiply the prices given above by the rate per kw. hour charged by the local electric light company, and that will give the cost for current for 1000 welds in any given locality.

welding machine is just as important as that of the operator himself, and the cost of such labor, together with the interest and depreciation on the purchase price of the welding machine and the cost of installing, are part of the overhead expense. Articles of special shapes will require different amounts of current and experiment alone will show the current required; this factor, with the labor and overhead expenses, will give the cost. It will be self-evident that the better provision one makes for handling the work, the lower will be the cost per unit produced.

Strength of the Weld. The strength of the weld should equal from 75 per cent of the original material on heavy stock up to 95 per cent of it on light stock, when finished to the same diameter or thickness as the piece; this can be made 100 per cent or greater, if a reinforcement can be left on in the form of an upset. The strength of a weld is slightly increased by working after welding, unless there is too much carbon or silicon in the iron. The metal is not damaged by welding with either the butt- or spot-welding systems, if properly done, because the heat can be controlled so exactly. The oxide which may be present at the joint is usually forced out into the upset and ground off; so a burned weld is a rare thing with this system. In the early days of the Thomson system, there were complaints of weak spongy burnt welds, when made by butt welding, but this was largely due to inexperience and the tendency to heat the metal too much. If an excess of heat is applied, either by using too high a current or leaving it on too long, the metal may be weakened within the heating radius and break about an inch from the joint.

Watertown Arsenal Tests. A number of years ago, a series of tests on electric welding was conducted at the Watertown Arsenal, and the following results were reported in the *Transactions of the American Society of Mechanical Engineers* for 1898:

> Wrought-iron welds averaged from 5 per cent to 10 per cent below that of the plain bars and the fractures were either fibrous or slightly spongy.
>
> Steel welds showed a strength of only from 20 per cent to 50 per cent of the original.
>
> Steel welded to wrought iron showed a strength equal to the iron.
>
> Copper showed a strength of from 90 per cent to 95 per cent of the original stock.
>
> Brass and wrought iron gave very uncertain welds and low strength.

Out of sixty samples welded, twenty-nine broke in the weld; seventeen, within two inches of the weld; eleven, within the range of moderate heat; and two broke near the grips of the testing machine. Some of the steel welds were almost as strong as the bars and some of the iron welds were of slightly greater strength than the bars; so it will be seen that welding by this system compares very favorably with other methods of welding.

Manufacturers of Butt and Spot Welders. There are several firms making butt- and spot-welding apparatus in this country today and it will pay the student to get data from all of them. The principal companies are the Thomson Electric Welding Company, Lynn, Mass.; Geuder, Paeschke & Frey, Milwaukee, Wisconsin; National Electric Welder Company, Warren, Ohio; Toledo Electric

Welder Company, Cincinnati, Ohio; Winfield Electric Welding Machine Company, Warren, Ohio, and the Standard Welding Company, Cleveland, Ohio. All of these makers have certain forms of machines which are adapted to particular lines of products, and they make a specialty of designing machines for any service capable of being performed by this system of welding.

GAS WELDING AND CUTTING

General Features of Method. Hot-flame, or gas, welding and cutting has been a practical process for so long that there is no very clear record as to just when it first came into commercial use, but the development and exploitation of apparatus for the generation and use of gases for welding during the past ten or fifteen years has given an added impetus to the art and it is now used in many ways which were not originally contemplated. The process of gas welding consists merely in joining metals by fusing them together at the point desired through the use of a high temperature gas flame as the source of heat. Various gases and combinations of gases are used and several types of apparatus are now on the market for the purpose. Cutting by the flame is a later development than welding and is both rapid and economical.

Defining Terms. There are two methods of welding in general use, the "Autogenous" and the "Heterogeneous", the names indicating clearly the main difference. The word "autogenous" signifies that the weld is made by the fusion or junction of the articles themselves, without the use of outside filling material to complete the joint. The word "heterogeneous" means a mixture, and signifies that the weld is made by fusing-in some sort of additional filling material, instead of depending entirely upon the metal of the pieces themselves. It is obvious that, if the filling material is of a metal different from the pieces welded, we still have heterogeneous welding; so this name can be correctly applied to brazing or soldering. Custom makes laws, it is said, and custom limits the term "welding" to cases where the same metal is used for a filler as is used in the article welded, and that is the way the term used here. The term "autogenous" has unfortunately come to be applied to all forms of gas welding, and some confusion has resulted because the statement is made that neither flux nor hammering is necessary with that process. The truth is that fluxes are very beneficial when welding some metals and hammering helps the strength of welds in heavy pieces because it tends to change the structure of the metal from a crystalline to a fibrous nature. Further reference will be made to this later, when discussing methods of welding.

Combinations of Gases with Oxygen. The gases originally used for welding were probably oxygen and hydrogen, and efforts to liquefy them were made about one hundred years ago in order to simplify the means of storing them. It took about fifty years to develop a good process for doing this and resulted in the development of one of the principal present-day methods of producing oxygen. Most of the welding today is done with systems using oxygen in combination with another gas; and the processes take their names from the gases used. The leading processes are known as the oxy-acetylene, oxy-hydrogen (or oxy-hydric), oxy-pintsch gas, blau-gas, water-gas and coal-gas welding processes, the oxy-pintsch-gas process being the latest development. All of these processes depend upon the use of compressed gases, usually stored in strong cylinders and mixed in a burner or torch as used, and may be used for either cutting or welding.

Advantages Claimed. The principal advantages claimed for gas welding are: the simplicity of the process; low first cost of the apparatus; wide range of applicability; light weight of the parts; ease of portability, if necessary; high temperature of the flame; and flexibility of the process for heating purposes. The limitations of the process are: the danger from using an exposed flame; the liability of explosion of the gas tanks and generators; oxidation or carbonization of the weld by the flame; crystallization and cracking of the weld when cooling; and high cost of operation as compared with electric welding. The danger from explosions is being reduced gradually by improved apparatus and the restrictions imposed by the Board of Fire Underwriters.

In manufacturing plants and large repair shops, stationary plants for the generation of acetylene are generally used and the oxygen is purchased from companies making it on a large scale, but some of the larger concerns also make their own oxygen. The same rule applies to the gases used for other processes of welding than the oxy-acetylene. Small portable outfits are also made for moving about shops which do comparatively little welding, tanks of gas of the proper kind being mounted on substantial trucks. In a few cases small gas generators are mounted on the trucks, but these offer but little advantage over the tanks and are more expensive and harder to handle.

GASES USED FOR WELDING

Gases and their sources form a very important part of the study of the gas-welding processes, because a knowledge of these will often be of great value in determining the best process for particular purposes. This is becoming more necessary because so many concerns are installing their own generating plants in order to get their gases cheaper and more promptly than is otherwise possible. The gases used in hot-flame welding today are acetylene, blau gas, coal gas, hydrogen, oxygen, pintsch gas, and water gas, and various methods are in use for their production and storage.

About one hundred years ago, considerable experimenting was done by the leading physicists to determine the best methods of obtaining the various gases on a commercial scale, and to discover how they might be compressed or even liquefied, with the result that many of the gases in use today for welding were produced on a commercial scale and their value for heating purposes demonstrated, many years ago.

Acetylene (C_2H_2). Acetylene is a colorless gas with a very disagreeable odor, very largely due to the impurities present. It was first obtained by Davy in 1837 when making potassium. Berthelot produced acetylene in 1858 by passing hydrogen through an electric arc, and Wohler produced calcium carbide in 1862 by fusing lime, zinc, and carbon together and then obtained acetylene by adding water to the carbide. Acetylene was first liquefied by Cailletet in 1877 and the use of compressed acetylene was developed by Claude and Hesse. Today, acetylene is obtained almost exclusively from calcium carbide and water, and great care must be exercised to see that pure carbide is used in order to prevent the generation of phosphureted hydrogen along with the acetylene.

Calcium Carbide (CaC_2). Calcium carbide is a dark gray slag formed by fusing lime and coke in the intense heat of an electric furnace; it possesses a great affinity for water. When calcium carbide is combined with water (H_2O), in the proportion of 2 parts water to 1 part carbide, a chemical reaction takes place which heats the mass and forms acetylene (C_2H_2) and lime ($CaOH_2O$) in the form of ashes. In other words, the carbon combines with the hydrogen to form acetylene and the calcium combines with the oxygen to form lime. One pound of carbide will yield about $4\frac{1}{2}$ cubic feet of acetylene.

Calcium carbide alone is not an explosive and it will not explode even when exposed to the highest heat but, unless it is kept dry, it will absorb moisture and generate acetylene, which is explosive. This is why it is best to store calcium carbide in air-tight tins.

Methods of Storing Acetylene. When mixed with air, acetylene is explosive over a long range of proportions and this makes the gas very troublesome. It is explosive over the limits of 2 per cent gas and 98 per cent air up to 49 per cent gas and 51 per cent air and, when mixed with oxygen, it burns with a tremendous heat. Acetylene dissociates at 780 degrees centigrade into carbon and hydrogen and, when under a pressure of two atmospheres (30 pounds) or more, it is tricky and liable to explode; so it is sometimes stored in specially prepared tanks. Acetylene is readily soluble in liquid acetone, which is cheap, inert, and incombustible; so storage cylinders or tanks are filled partly full of it and then the acetylene gas is compressed into it. Acetone at atmospheric pressure and a temperature of 15 degrees centigrade will dissolve 24 times its own volume of acetylene and, at 12 times atmospheric pressure (180 pounds), it will dissolve about 300 times its volume of acetylene and expand about 50 per cent. The cylinders are partly filled with asbestos fiber to carry the acetone and, to fill the cylinder, it is merely necessary to charge it with compressed acetylene. The various types of acetylene generators will be described later.

Blau Gas. Blau gas is liquefied illuminating gas and is produced by the distillation of mineral oils in red-hot retorts. It contains the same elements as ordinary coal gas but in different proportions; it is free from carbon oxide and is therefore not poisonous. It contains carbon and hydrogen in the proportion of about 5 parts of carbon to 1 part hydrogen and will develop about 20 per cent more heat units than acetylene. Blau gas, named after its inventor, can be compressed and liquefied; when liquefied it occupies but 1/400 part of its gaseous volume and is usually sold under a pressure of

100 atmospheres, in steel cylinders. It is very inert and therefore difficult to explode, the range of explosiveness being from 4 per cent gas and 96 per cent air up to only 8 per cent gas and 92 per cent air. This gas is already used quite extensively abroad, and is beginning to be used more and more in this country.

Coal Gas. Coal gas, or illuminating gas, is produced by the destructive distillation of coal and its discovery dates back to 1727. It is made by heating coal to the point where it decomposes in a closed retort in order that the gas, tar, and other constituents may be saved. Bituminous coal is better for gas making than anthracite because it softens or fuses at a temperature much lower than that required for combustion and this fusion is the commencement of the destructive distillation which forms the solid, liquid, and gaseous compounds from the coal. The operation takes place in specially constructed furnaces and the gas is carried to storage tanks after being washed to remove impurities. One ton of coal will produce about 10,000 cubic feet of gas, 1400 pounds of coke, 12 gallons of tar, and 4 pounds of ammonia, the operation lasting about 4 hours. The gas contains about 5 per cent of hydrocarbon vapors, 13 per cent of carbon oxides, 31 per cent marsh gas, 46 per cent hydrogen, and 5 per cent nitrogen with traces of oxygen, and has a heat value of about 40 per cent that of acetylene. Its use for welding is limited to metals of low melting points and is gradually being superseded by other gases.

Hydrogen. Hydrogen is one of the elements and is the lightest substance known. It is obtained by the decomposition of water into oxygen and hydrogen, both gases being collected and used. Hydrogen is also prepared by passing steam over coke heated to a dull red. If the temperature is not too high, carbon dioxide and hydrogen will be formed ($C+2H_2O=2H_2+CO_2$) but the carbon dioxide may be removed by passing the gas through a vessel of slaked lime. Hydrogen may be liquefied and, when mixed with air or oxygen, is explosive. It is not poisonous but may cause death if inhaled because it will exclude oxygen from the lungs. When hydrogen and oxygen are mixed to form a gas in welding and cutting, they produce a temperature of about 2500 degrees centigrade.

Oxygen. Oxygen is the most important of all of the elements and is used as one of the gases in nearly all welding processes. It was discovered in 1774 by Priestley and Scheele, both working independently, and in 1789 Lavoisier proved that its presence was necessary for combustion in the air. Oxygen was liquefied in 1877 by Pictet at a pressure of 320 atmospheres.

Methods of Commercial Production. Oxygen is produced commercially by three methods: from the air by liquefaction and fractional distillation; from water by electrolytic action; and from potassium chlorate. The production of *oxygen from air by liquefaction* is by far the greatest source of this gas today for welding purposes, though electrolytic apparatus has recently been developed which is making a strong competitor where power is cheap. The oxygen used for welding must be free from chlorine, although the usual mixture of 5 per cent of nitrogen and from 2 to 3 per cent of hydrogen is no disadvantage. Its production is not a very complicated process, but the apparatus is rather expensive, and only those plants requiring 1000 feet or more per week can afford to make their own gas.

The principal process for producing oxygen from the air is that developed by Linde and consists in liquefying the air and separating the nitrogen and oxygen by fractional distillation, similar to rectifying spirits. The air is first compressed to 1800 pounds per square-inch pressure, and cooled by ice and salt, or ammonia. When the air is compressed, as stated, its temperature rises because of the compression and must be cooled before the compression is continued. The air is, therefore, allowed to expand, thereby cooling itself; then it flows back over the pipes containing the oncoming air, thus cooling the whole body of air. This cool air is again compressed and expanded, growing colder with each expansion, until it is sufficiently near 350 degrees Fahrenheit so that the final expansion to atmospheric pressure liquefies it. Liquid air is 80 per cent nitrogen and 20 per cent oxygen, and commercial oxygen is 95 per cent pure. The balance is nitrogen and is not harmful for welding purposes.

Oxygen is sold in tanks containing 5, 25, 50, or 100 cubic feet, as desired, and the tanks themselves may be either bought or rented. They can be recharged when empty, and each tank is equipped with a reducing valve to regulate the pressure when using. A pressure gage must also be used, when using the oxygen, and leakage must be looked out for because of the high pressure.

The production of oxygen by the *electrolytic decomposition of water* is the method used most in Europe and gives two volumes of hydrogen to one of oxygen. The process consists in passing an electric current at a pressure of 2 or 3 volts through an electrolyte or solution of sodium or of potassium hydroxide. Direct current is used and oxygen rises from the water around the positive terminal plate and hydrogen from around the negative plate, each gas being conducted through separate pipes to compressors for storage. The tank, in which the electrolytic action takes place, is usually of cast iron and is divided into two sections by a partition running part way down. One terminal is placed in each section, and the temperature is maintained at about 165 degrees Fahrenheit because the action requires a lower voltage at this temperature than at any other. From 240 to 325 amperes are used and the gases are about 99 per cent pure. Purity is important because foreign elements may burn into the metal when welding.

The apparatus for making *oxygen from potassium chlorate* is comparatively simple and low priced and is especially suitable for use in out-of-the-way plants doing welding. The process is based on the fact that, when potassium chlorate is heated, it produces a somewhat large percentage of oxygen of 97 to 98 per cent purity. In order to prevent the chlorate from melting and flashing under heat, about 13 parts of manganese dioxide are mixed with each 100 parts of the potassium chlorate, and the gas is given three scrubbings before storing. The mixture is first packed tightly into a retort, heated slowly with a gas flame, and the oxygen is carried through three washer tanks, filled with a solution of sodium hydroxide, and then into a gasometer. From here it is compressed into steel cylinders at 300 pounds per square inch for service. The makers of this apparatus claim that there is but little oxygen lost through leakage because of the low pressures used; that but little oxygen is lost in recharging the retort for the same reason; and that the gas is thoroughly washed in the scrubbers because the bubbles are so large. One pound of chemicals costing about 8 cents will produce about 4½ cubic feet of oxygen at a total cost for everything of about 2¼ cents per cubic foot of gas.

Pintsch Gas. Pintsch gas was originally developed for lighting purposes and is used for lighting steam railway cars. It is an oil gas made from crude petroleum or similar oils and will safely stand a high degree of compression, it being used at various pressures for different purposes. Works for the supply of the gas are now established in nearly all of the large cities in the United States, Canada, and Mexico and gas can be obtained in pressures up to 100 atmospheres (1500 pounds pressure per square inch). It can also be obtained in flasks at 12 atmospheres (180 pounds pressure), but it is used at about 25 pounds pressure for cutting and welding. On account of its high heating value and its stability, or resistance to pre-ignition, it is coming into use for high temperature work in conjunction with oxygen and bids fair to become a serious competitor of acetylene.

Water Gas. Water gas is a mixture of carbon monoxide and hydrogen and is formed by passing steam over or through incandescent coke, thus causing the steam to decompose into oxygen and hydrogen. The oxygen combines with carbon from the coke and forms carbon monoxide, with a little carbon dioxide, and a slight impurity in the form of hydrogen sulphide from the sulphur in the coke. The impurity can be removed with lime or iron oxide, as when making coal gas. Thirty-five pounds of coke are used for each 1000 cubic feet of gas, on an average, and the composition of the water gas is approximately as follows:

Hydrocarbons and vapors	14%
Carbonic oxides	31%
Hydrogen	31%
Oxygen	1%
Methane	20%
Nitrogen	3%
	100%

The apparatus used for generating water gas is comparatively simple and consists mainly of a generator and a superheater, with connections for taking off the gas and for the supply of air and steam. Water gas gives an extremely high temperature when burned and is used a great deal in Europe for heating metals preparatory to welding by hammering as well as for fusing, as in some other processes. Owing to its lack of odor when pure, it is dangerous if it escapes.

OXY-ACETYLENE WELDING

General Features. The oxy-acetylene welding process is the best known of the hot-flame systems and is based on the combustion of oxygen and acetylene at the tip of a torch as the source of heat. This process has apparently been developed to the highest possible degree and is probably the most efficient of the various hot-flame systems in general use, the flame having an approximate temperature of 3500 degrees centigrade. The practical value of this process was overestimated, when it was first introduced, and there are still many limitations to be overcome but improvements in torches, valves, generators, and storage tanks are being made and should result in improving its status. Owing to the low first cost, there are thousands of oxy-acetylene plants in use for welding and cutting, in spite of the high cost of operating, and reductions in the cost of the gases will eventually bring down the cost of operation to a more reasonable basis.

The principal elements of an oxy-acetylene installation are: the oxygen generating or storing apparatus; acetylene generating or storing apparatus; and the burner or torch with its connections. For large plants it will pay to install oxygen generating plants as well as the acetylene plants, but in other shops the oxygen is usually purchased in steel tanks and the acetylene is generated in small-sized outfits. For moderate sized shops a portable outfit can be used, consisting of an oxygen tank and a small acetylene generator, or an oxygen tank and an acetylene tank on an ordinary hand truck.

Acetylene Generator. The acetylene generator is a comparatively simple device, usually a single steel receptacle for holding the gas, with various attachments for controlling the action of the water on the carbide. There are two general systems of acetylene welding in use, the high pressure system and the low pressure system, both of which have their advocates. As a matter of fact, the so-called high pressure system, used in this country today, is a medium pressure system, the true high pressure system being used principally in France and not yet having been introduced commercially into this country.

Acetylene generators are made in five types, one of which only is used to any great extent for making acetylene for welding use. These are the "dip", the "drop" or "plunge", the "overflow", the "rescission", and the "spray" types, the drop type being the one most used.

Dip Type. The dip generator is so arranged that the calcium carbide is suspended in a sort of basket inside the gas holder and, as the gas is used, the basket is lowered until the carbide comes in contact with the water. More acetylene is then generated and this causes the pressure to raise the holder and basket, thus stopping generation until the gas is used.

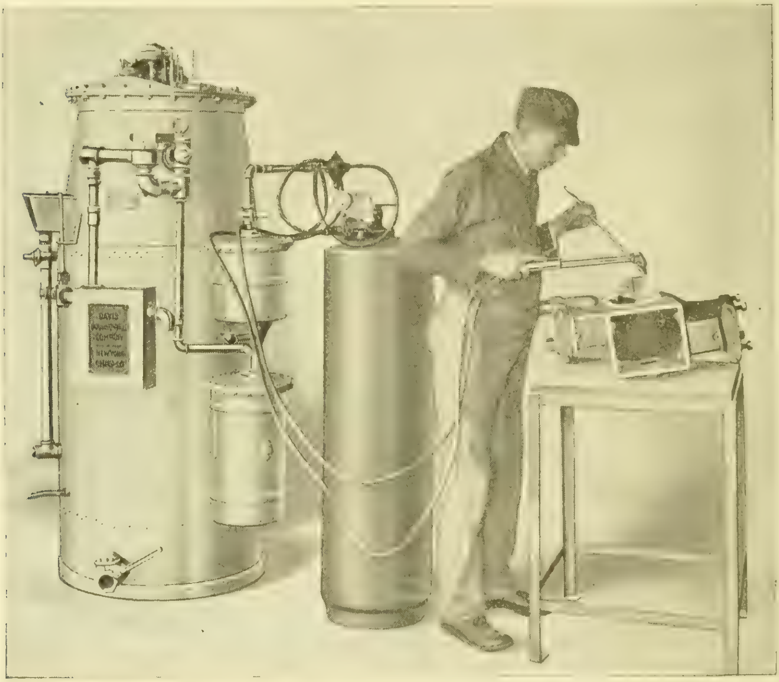


Fig. 112. 100-Pound Oxy-Acetylene Welding Outfit
Courtesy of Davis-Bournonville Company

Rescission Type. The rescission generator is similar in principle to the dip type, the only important difference being that the gas pressure forces the water away from the carbide basket instead of lifting it.

Overflow Type. The overflow generator has the carbide in a series of compartments, the water filling the first before overflowing into the second, then into the third, etc., until all of the carbide has been flooded.

Spray Type. The spray generator is one of the oldest types and has a pan of carbide located so that the water may drip into it from above. The supply of water is cut off when the gas pressure becomes too high and steam is frequently formed by the high temperature of the reaction. These machines are wasteful and dust from the carbide may clog the pipes and burner.

Drop Type. The drop or plunger type of generator is the most economical and satisfactory and has practically superseded all of the others. This type of generator is arranged so that the carbide falls a few lumps at a time into a large vessel of water, the feeding being done by suitable mechanism; the water absorbs the heat so rapidly that the gas is kept cool and the temperature of the entire outfit is much lower than with other types. The gas is washed by bubbling up through the water and the lime remains in the bottom and is frequently removed. This lime makes a good fertilizer. It has been claimed that this type of machine is inefficient because the water will take up gas at the rate of 1 cubic foot per cubic foot of water; but as the water becomes saturated with the lime, it causes the gas to pass out, so that only about three per cent of the gas is actually lost by this action. Theoretically, 1 pound of carbide requires ½ pound of water but, in practice, it takes about 1 gallon to the pound for the best results and should produce 4½ feet of gas.

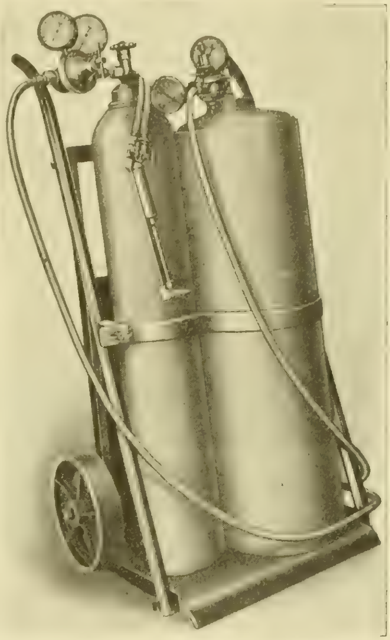


Fig. 113. Portable Welding or Cutting Oxy-Acetylene Unit
Courtesy of Davis-Bournonville Company

The best known acetylene generator on the market in America today is the Davis generator made by the Davis-Bournonville Company, New York, for use in connection with their welding apparatus, Fig. 112, made under the Bournonville patents. The carbide is fed into the machine through a hopper at the top in the form of lumps, because ground carbide will produce less gas, the carbide being dropped into the water as required. The feeding mechanism is on top and operates through variations in the gas pressure and through its effect on heavy weights and a moving gas bell. Attached to the tank are also a filter, flash-back chamber, drainage chamber, water filling tube, blow-off valve, and such other devices as are required for the safety and operation of the generator. The pressure of the gas may be varied and can be made to run up to 15 pounds if desired. These machines are made in sizes from 20 pounds carbide capacity up to 300 pounds capacity, a small-sized portable outfit being shown in Fig. 113.

Oxygen Generator. Oxygen generators are much more elaborate devices than acetylene generators and the methods of action of the large types have already been given on pp. 98 and 99. Most of the small plants, whose details may be easily understood, are for making oxygen from chlorate of potassium and consist of a generator, washer, gasometer, and compressor. The generator for the oxygen consists of a metal retort and a gas burner for heating it and the chlorate is mixed with a little manganese dioxide and heated in the retort. The vapor from this is usually carried through three scrubbers, consisting of barrels filled with a solution of sodium hydroxide, thence into a gasometer or tank to be stored until required. From the gasometer the oxygen is carried to a compressor, usually two-stage and there compressed for filling the cylinders at 300 pounds pressure per square inch. Oxygen of high purity can also be generated by wetting sodium peroxide; small outfits of this type have been put on the market under the name of "Oxone".

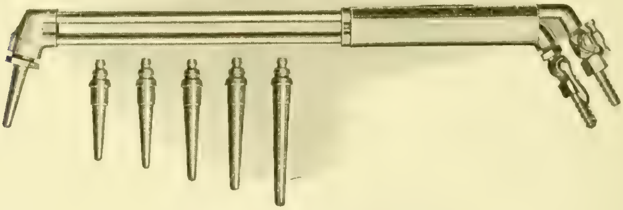


Fig. 114. Medium Welding Torch
Courtesy of Davis-Bournonville Company

Torch. The torch is the next item of importance in any good acetylene welding outfit and upon the development of this device alone depended the success of the oxy-acetylene process to a large extent. It has taken years to bring torches to their present state for the flame is very hot and the gases are highly explosive, yet they must be mixed and controlled accurately. The oxy-acetylene torch was probably invented by Fouche and was a high pressure device; so it was comparatively easy to get a good mixture but, later, it became necessary to develop a torch for low pressure work and it proved to be a difficult matter. It was done, however, and there are now three styles in use: the original high pressure torch, the medium or positive pressure torch, Fig. 114, and the low pressure torch. There is also a special torch for cutting with an extra oxygen feed in addition to the regular flame feed. The gases are regulated by cocks at the handle, and wire gauze is placed in the passages to prevent flashing back in case of too low pressure, somewhat on the principle of the miner's lamp. Torches are made in several sizes and have a series of removable tips to provide for various sized flames. Goggles for the eyes and gloves for the hands of the operator are necessary for his protection.

Automatic Cutting and Welding Machines. A recent development in connection with oxy-acetylene apparatus is the use of special cutting machines and welding machines which work automatically and displace hand welding and cutting. An attendant is necessary, of course, to see that the material is properly placed but the machine does such a high quality of work at such a uniform rate that it can turn out work of a simple nature more quickly and more cheaply than when done by hand. With this machine any irregular pattern may be cut quickly and accurately and it will cut steel 3 inches thick at the rate of 6 inches per minute. The welding machines are especially valuable for work on pipes, barrels, cylinders, cans, and other articles which are all alike, and some very efficient special machines have been built for such service. These automatic machines are not of any value for repair work, to be sure, and do not warrant the cost for any other than repetition or straight work. The torch is carried on an arm which is moved by the mechanism of the machine.

Process of Welding. *Adjusting the Flame.* The process of welding with the acetylene flame is similar to that of using the graphite electrode in electric-arc welding, as the flame is the source of heat and the filling material must be added as melted, but it has the disadvantage of being an open flame, which presents a certain element of danger. The first thing the operatorhas to do is to learn how to adjust his flame, and this is not easy because there is no rule for the exact proportion of oxygen and acetylene. It is approximately 1 part acetylene to 1.5 partsoxygen for most purposes. If the oxygen is as great as 2.5 against 1 of acetylene, an oxidizing flame will be produced which will probably cut the metal; if there is too much acetylene to be all consumed in the flame, itwill split up and allow carbon to enter the weld and carbonize it. The flame should be so adjusted that the two cones formed in the flame unite into a single small one. In operation, the tip of the white cone in the flame should just touch the metal and the hand should be held steady because, if the tip of the torch should touch the work, it will cause a flash back and necessitate relighting, if nothing worse. The torch should be given a sort of rotary motion around over the surface of the weld, with a slight forward and upward movement, in order to blend the metal and reduce the liability to overheat it.

Care for Expansion During Heating. All welding operations, whether with gas or electricity, should be undertaken only after a careful consideration of the effects of expansion and contraction on both the joint and the piece welded. This is especially important when welding castings, and even more so with the oxy-acetylene system than with the electric-arc system, because of the necessity for heating a comparatively large surface around the weld.

Preheating. Cast-iron pieces and articles of circular or closed shapes, such as wheels, should be preheated before welding and reheated afterwards to relieve any stresses which may be set up in them. Gas furnaces or oil burners make good preheaters as they are much cheaper than using the oxy-acetylene flame for heating preparatory to welding. Heating is necessary for practically all kinds of materials in order to prevent chilling of the flame and consequent loss of efficiency. It is also necessary to choose the proper sized tip to suit the work.

Conditions of Metal and Joint. It is important to have the surfaces clean before starting to weld and, if the parts have been cut with the flame, they must be chipped off in order to remove the oxidized material before being welded. Plates, to be welded should be beveled on the edges, unless they are less than ⅛ inch thick and filling material of similar composition used for the joint. If the plates are over ½ inch thick, it is advisable to bevel from both sides towards the center in order to balance the shrinkage strains and reduce the amount of filling required. The edges of the bevel should be from 30 to 45 degrees angle and the plates should be spaced slightly apart to insure filling clear through the joint. The opening should flare a little from the end where work begins to the opposite end in order to allow for the parts drawing together as the work progresses. Fluxes are an advantage in acetylene welding in order to absorb or reduce the oxide formed by the flame and to prevent burning out the carbon from high carbon steels, etc. They also protect copper and aluminum from oxidizing and reduce the liability of the zinc burning out of brass.

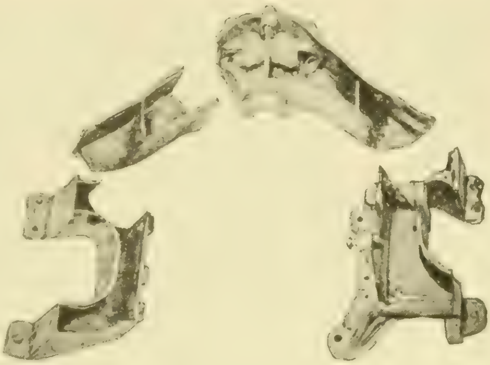


Fig. 115. Broken Aluminum Casting
Courtesy of Davis-Bournonville Company

Effects on Various Metals. *Aluminum* is very sensitive to oxygen; so an excess of acetylene in the flame is desirable when welding it. The metal does not run readily and must be puddled into place with a rod of iron. It should be hammered to toughen after welding, has a low melting point, and is difficult to weld. Figs. 115 and 116 show a successful piece of work with an aluminum casting.

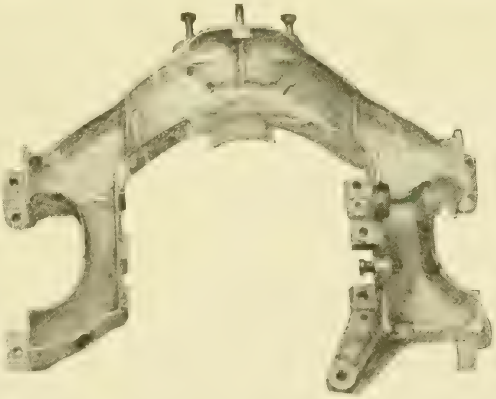


Fig. 116. Aluminum Casting Welded by Gas Torch
Courtesy of Davis-Bournonville Company

Brass can be welded readily with a moderately large flame, but the cone of the flame should be kept away from the metal. Borax is used as a flux for brass and the weld is usually not very strong because the material after being melted is merely cast brass.

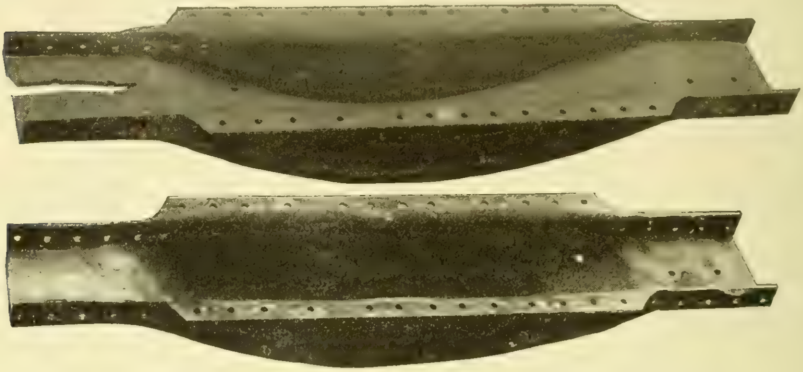


Fig. 117. Split Steel Bolster Welded by Gas Torch
Courtesy of Oxweld Acetylene Company

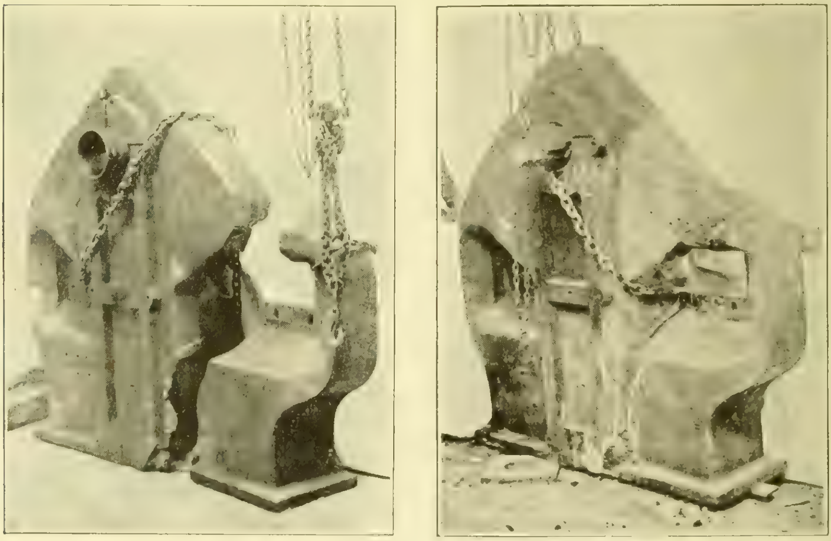


Fig. 118. Immense Shear Casting Broken and Welded by the Gas Torch
Courtesy of Davis-Bournonville Company

Copper should be welded with a low temperature flame and hammered afterwards to restore its toughness. Acetylene attacks copper, so care must be exercised to see that there is no excess in the flame as it may form acetylide of copper, which is a fulminate and can be exploded by striking with a hammer, or even by high friction.

Cast iron can be welded but is very liable to crack when cooling, so careful preheating is necessary before welding and slow cooling afterwards. High silicon cast-iron melt-bars, which are low in sulphur and phosphorus, are used, and borax forms this flux. Cast iron runs freely and a mold should be made around the spot to be welded to retain it, and the work must be done horizontally.

Wrought iron becomes cast iron when it cools—unless it is very low in silicon—and as it loses its structure it should be hammered to toughen it. It does not readily melt to a fluid but becomes a sort of thin paste and must be worked into place with the melt bar.

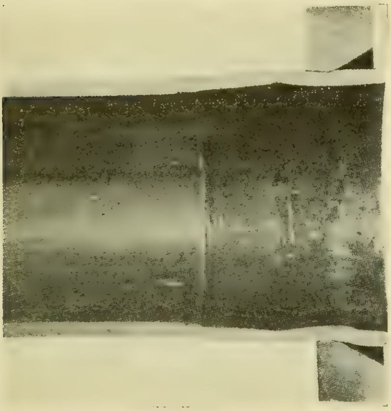


Fig. 119. Section of Boiler Flue Ready to Weld
Courtesy of "The American Machinist"

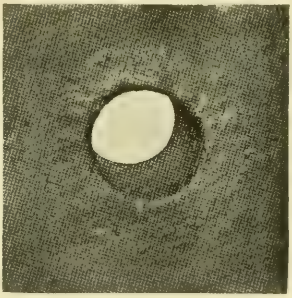


Fig. 120. Welded Boiler Flue
Courtesy of "The American Machinist"

Steel, with a small percentage of carbon, welds more easily than high carbon steel, and the carbon is liable to burn out or so change its structure near the weld as to destroy its essential properties. High carbon steels require careful heat treatment after welding to restore their original properties, and soft steel should be hammered to toughen it. Steel may be welded to iron or copper by proper manipulation but these are uncertain operations and are very seldom necessary.

Alloys of nearly all kinds may be welded with oxy-acetylene apparatus; the principal point to look out for is to be sure that the composition of the alloy is known before starting. If the flame is adjusted to suit the most sensitive metal and its action watched, there should be no serious trouble.

Applications of Oxy=Acetylene Welding. The applications of oxy-acetylene welding are almost as numerous as are the articles to be welded and apparatus of this type is in use in almost all lines of manufacture and repair. The low cost of the apparatus helped to give this system its present foothold and in many lines it has given entire satisfaction, especially on light work and where convenience is of greater importance than the cost of operation. Castings, forgings, sheets, and tubes of iron, steel, Fig. 118, copper, aluminum, etc., may be welded within the limitations just mentioned, and there is apparently no limit to the size of the piece which may be handled successfully, Fig. 118. Large articles cost more in proportion than small ones because of the greater amount of heat wasted in keeping them hot, but users of the system weld practically everything that comes along. Steel tanks are frequently welded instead of being riveted; car roof seams are welded instead of being soldered; steel furniture is welded in all the joints; cracked cast-iron cylinders are welded; boilers are patched and the flues welded in, Figs. 119 and 120; engine frames, crank cases, and automobile frames are repaired by welding. A good weld is stronger than a riveted joint and the cost is about the same.

Cost of Acetylene Welding. The cost of acetylene welding is very moderate on work of small or medium size but it becomes somewhat high on large work on account of the relative amount of heating to be done while welding. However, the advantages to be gained in quantity of production and even more so in cases of repairs because of the cost of new pieces, makes the system very valuable in many establishments. The cost of welding sheet steel per foot of length of seam is given in Table XIV and it will be interesting to compare this with the cost of doing the same work with the electric-arc system. This table was furnished by the Davis-Bournonville Company.

Repair Work. It is difficult to get accurate figures on the cost of doing miscellaneous repair work because the average repair man does not like to tell, but the following are the charges made in one automobile repair shop and will give an idea of what such work costs because the profits charged are usually 100 per cent of the cost.

TABLE XIV

Approximate Cost of Oxy-Acetylene Welding

Tip Number	Thickness of Metal in Inches	Consumption of Acetylene in Cu. Ft. per Hour	Consumption of Oxygen in Cu. Ft. Per Hour	Proper Pressure in Pounds for Oxygen	Lineal Feet Welded Per Hour	Cost of Labor Per Hour	Total Cost Per Hour	Cost per Lineal Foot
1	$\frac{1}{32}$ to $\frac{1}{16}$	2.8	3.6	8 to 10	50	$0.30	$0.436	$0.0087
2	$\frac{1}{16}$ to $\frac{3}{32}$	4.5	5.7	10 to 12	30	.30	.516	.0172
3	$\frac{3}{32}$ to $\frac{1}{8}$	7.5	9.7	12 to 14	25	.30	.666	.0266
4	$\frac{1}{8}$ to $\frac{1}{4}$	11.7	15.	14 to 18	16	.30	.867	.054
5	$\frac{1}{4}$ to $\frac{5}{16}$	18.	23.	18 to 22	10	.30	1.17	.117
6	$\frac{5}{16}$ to $\frac{7}{16}$	25.	32.	20 to 25	7	.30	1.51	.216
7	$\frac{7}{16}$ to $\frac{1}{2}$	32.5	41.5	22 to 27	5	.30	1.87	.374

NOTE: The acetylene is used at a pressure of about 3 lbs. per sq. in. The cost of oxygen is estimated at 3 cents, and of acetylene at 1 cent per cubic foot. Labor is estimated at 30 cents per hour.

Welding axles, from	$2.00 to	$5.00
Cracked cylinder water jackets	8.00 to	12.00
Broken cylinder lug welded on	2.00 to	4.00
Cylinders cracked inside	12.00 to	20.00
Broken crank case, aluminum	5.00 to	20.00
Main side frames broken, each	15.00 to	25.00

Defects, known as "cold shuts", frequently develop in steel forgings and the average cost of welding these is from 50 cents to $2.00 each. Engine connecting rods have been welded at $3.00 to $12.00 each, depending upon the size. Stern posts of vessels frequently break during storms and these can be welded for $35.00 on small ones up to several hundred dollars for large ones. Blow holes in iron castings cost 25 to 75 cents to fill in.

The following figures on various repair jobs have been compiled by the Oxweld Acetylene Company, Chicago, and cover a wide variety of work:

Welding stern post of lake steamer "Mullen"	$32.00
General repairs on Cahall water tube boiler	29.49
Small cast-iron gas engine frame, sand spot in one side	.40
Broken locomotive side rod, steel forging	5.22
Short crack in locomotive side sheet, 4 inches long	2.50
Cracked locomotive mud ring, nine hours	22.00
Small patch in side sheet of locomotive fire box	10.01
Medium sized patch in side sheet of fire box	17.38
Three short cracks in fire box sheets, 11 inches total	3.46
Small repairs to steel railway motor case	8.82
Welding lugs on small shaper arm, steel casting	4.50
12-inch crack in end of pressed steel car bolster	6.16
Crack in cast-steel truck side frame, "Andrews" truck	.85
Welding small lug to cast-iron cylinder head	5.89
Patch on side of aluminum crank case for automobile engine	1.50
Cutting risers from large steel castings, per sq. in	.014

In conclusion, the student is urged to familiarize himself with the rules laid down by the National Board of Fire Underwriters concerning the installation, care, and operation of oxy-acetylene and other types of hot-flame welding apparatus. The complete rules are too lengthy for reproduction here, but a copy can be obtained from the headquarters of the Board in Chicago and will be interesting reading.

OXY-HYDROGEN WELDING

The use of oxygen and hydrogen as the gases for welding and cutting is older than the oxy-acetylene process and dates back to before the production of oxygen by either electrolysis or liquefaction of air. Oxygen was probably generated in those days from potassium chlorate and manganese dioxide, or perhaps from potassium and sodium peroxides and water, and the hydrogen from hydrochloric acid and zinc. The oxy-hydrogen process was developed by Newman who used detonating gas (pure oxygen and hydrogen mixed) at a pressure of about 3 atmospheres. This gas is still used to some extent in welding platinum, lead, and precious metals but it is rapidly being superseded by apparatus designed to use the oxygen and hydrogen from separate cylinders.

Equipment. The apparatus required for oxy-hydrogen welding is similar to that in use for oxy-acetylene welding and consists primarily of the two steel cylinders for the oxygen and hydrogen (at pressures of 1500 to 2000 pounds per square inch); a mixer and insulator of the gases, together with a regulator; high pressure reducing valves for each of the gases; armored hose; and the special blowpipe, or torch. When the blowpipe is used, there are two tubes leading to it, one for the oxygen and the other for the hydrogen, and the blowpipe is made with an inner and an outer tube. The oxygen is carried through the inner tube and the hydrogen is carried through the outer tube and lighted first. After the oxygen is turned on, the flame is adjusted to suit the work in hand and the mixing is done in the tip of the blowpipe just before the gases enter the flame. Hydrogen and air can be used with the same sort of blowpipe for light work requiring but moderate heat, such as lead burning, but the process is much slower and more expensive than with the oxy-hydrogen flame.

For commercial welding another type of torch is used and the gases are combined in the mixer and carried to the burner through a single tube. This torch has an enlargement, where the gases enter, which reduces their velocity; from this chamber the gases pass through the smooth tubular body to the nozzle. The latter diminishes in size toward the tip and causes the gas to increase in speed up to the proper velocity.

Handling Oxy-Hydrogen Torch. The oxy-hydrogen flame is pale blue, almost colorless in fact, and has a temperature of about 2000 degrees centigrade. When lighting the torch, the hydrogen should be turned on about two-thirds and ignited; the oxygen should then be turned on enough to give a pale blue conical flame, and then the hydrogen should be turned on full. This will take but a few seconds, and a flame, which will not melt the metal too rapidly, is better than one of such intensity as to burn the work. The end of the cone of oxygen in the flame should never touch the work or that will burn it also. When through welding, the oxygen should be turned off first. Theoretically, two parts of hydrogen should be used for each part of oxygen but experience shows that it is desirable to use about three parts of hydrogen to one of oxygen. Some operators advocate using even more hydrogen, but this is not necessary when the gases are properly mixed before entering the flame.

Process of Oxy=Hydrogen Welding. The process of welding with oxy-hydrogen is similar to other hot-flame processes and the joints must be beveled in the same way to make them accessible for filling. The work should be heated first, in order to prevent chilling of the filling material, and the melt bar fused in to make the joint. In Germany this gas is used to heat plates and then they are welded by hammering, as in blacksmith work, this operation being used to a large extent in making large steel pipes. Iron, steel, copper, lead, zinc, and the other industrial metals can be welded by this process; the cost is similar to that for work done by the oxy-acetylene process, although somewhat higher for most operations. Each metal requires its own special method of treatment and the operator will soon learn the best ways of handling each job, but this process requires a skilled workman and the success or failure of the weld will depend largely on the man who does it.

Time Required for Weld. The time required for welding seams in steel plates will vary from two minutes per foot on $\frac{1}{32}$-inch sheets up to five minutes on $\frac{1}{4}$-inch plates. It is claimed that the oxy-hydrogen flame does not affect the ductility of the metal like the oxy-acetylene flame and, if this is true, it should be good for boiler repairs and other work in which this quality is desirable.

OXY=PINTSCH GAS WELDING

The use of pintsch gas and oxygen for hot-flame welding is the latest addition to the list of possible systems for general use, and was developed by the Safety Car Heating and Lighting Company, New York, primarily for use by steam railroads. It is as general in its applications, however, as any of the other systems and the fact that every railroad has pintsch gas on its cars and supply stations at frequent intervals should result in a wide application in shops which have no electric-arc welding apparatus. The principal feature of this process seems to be in the use of a special torch, as with the other gas systems, and the apparatus is similar.

Equipment. The apparatus consists of the two steel cylinders for the gases, valves for regulating the pressure, tubes for the gas, and the special torch. The pintsch gas is furnished at a pressure of 100 atmospheres (about 1500 pounds) and the oxygen at 150 pounds. The gas can also be obtained at 180 pounds pressure. The high pressure gas is reduced in two steps when used, the first being from 100 atmospheres to 14 atmospheres and then down to the 25 pounds required at the torch. The torches for this process are made to take the two tubes feeding the two gases and mixing them in a chamber at the back end, and a valve is provided in each inlet. The tip of the torch contains a preheater which operates by internal combustion and produces a high temperature, non-oxidizing flame. This feature of the torch is valuable and adds to the temperature of the flame.

The process of welding with the oxy-pintsch flame is the same as with the oxy-acetylene flame, but the manufacturers claim considerable saving in cost of operation. They give 3.4 cents as the cost of cutting one foot of an 18-inch channel $\frac{15}{32}$ inch thick, and the total cost of the work done on the channel was 86.2 cents against the old cost of $4.66 by drilling and chipping. No figures are available at this time for welding operations, but all sorts of articles can be successfully welded and cut by this process. The preparation of the joints should be the same as for other gases and the metal should be handled in the same way.

BLAU=GAS WELDING

General Advantages. The advantages claimed for the blau-gas process are safeness, cheapness, compressibility of the gas to a liquid, high B. T. U. (1800 per cubic feet), and convenience. On the other hand, the oxy-blau gas flame is not so hot as the oxy-acetylene and must be larger to do the same work. This is sometimes a disadvantage. This system is well established in Europe but has been adopted in this country only a few years and has not proved a very serious competitor of the other systems. Blau gas is distilled from fuel oil at only 600 degrees centigrade; so the hydrocarbon gases are not broken up and very little tar or methane is formed. During liquefaction for the market, the distillate is first subjected to two compressions which liquefy the low pressure gases and these are drawn off with the cooling water. The heavier gases are then compressed in two more stages and absorb most of the permanent gases when they liquefy.

Equipment Cylinders. The apparatus used for blau-gas welding consists of the regulation gas cylinders containing blau gas at 100 atmospheres pressure, cylinders with compressed oxygen, a gas expansion cylinder, pressure indicating and reducing gages, tubing, and high pressure torches. Owing to the blau gas being composed of gases of different critical pressures it must not be drawn from the top of the cylinders direct; so a tube extends through the liquid gas to the bottom of the cylinders and the heavier liquid is drawn off first. This expands in the expansion cylinder and blowpipe before entering the flame, and the lighter gases are drawn off last. The customary glasses should be provided for the workmen's eyes.

Torch. The welding torch has several sizes of tips and the cutting torch is so arranged that there is a preheating flame around the oxygen inlet. Liquid blau gas is first let into the expansion chamber at about 50 pounds pressure and then into the torch at from 10 to 20 pounds, depending upon the work to be done. The oxygen is led directly to the torch at pressures of 15 to 30 pounds for the various operations. Cutting requires higher pressures than welding.

Process of Blau=Gas Welding. The process of welding with the oxy-blau gas apparatus is similar to the other hot-flame systems excepting that its heating value is less and a larger spread of flame is required to give the required amount of heat units and temperature for the work. The explosive range of blau gas is 4 per cent and ranges from 4 parts gas to 96 parts air up to 8 parts gas and 92 parts air. Up to the present time its principal application has been to cutting, but it has been used for welding practically everything and a large amount of steel piping and tank work has been done with it. It is comparatively safe to use because it is chemically inert, nonpoisonous, and leaves no deposit in the pipes.

Water-Gas Welding. Water-gas welding is done by mixing oxygen with the gas and using it in a manner similar to the other gases. The gas is drawn from the mains and carried to the torch and there mixed with the oxygen for use. Its application is not very general because of its low heating value, but it is cheap when it can be obtained at all. It can also be obtained compressed into cylinders like the other gases but there is very little to recommend it for general use in view of the gradual reductions in cost of acetylene.

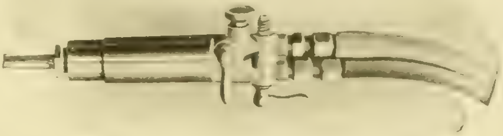


Fig. 121. Davis-Bournonville Cutting Blowpipe

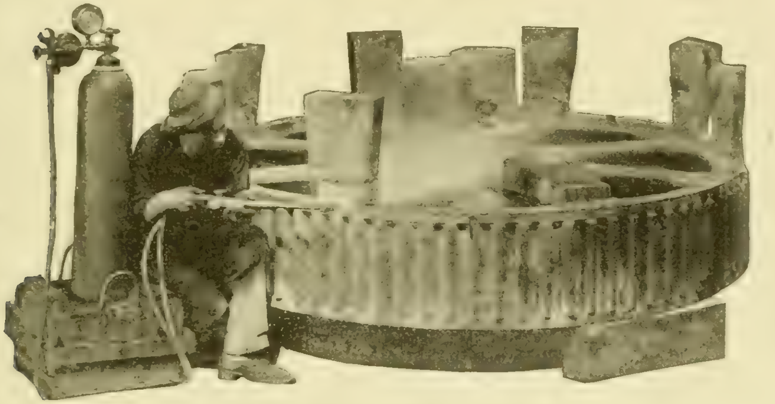


Fig. 122. Cutting Risers from Large Gear
Courtesy of Oxweld Acetylene Company

Fig. 123. Crosshead Slots Cut Out of Drop Forging
Courtesy of Oxweld Acetylene Company

CUTTING WITH GASES

All of the gases described for welding are also used for cutting and offer some advantages over other methods of cutting for various purposes. The work is done by heating the metal to about 1500 degrees Fahrenheit with a flame composed of oxygen and the gas used, and then directing a blast of oxygen against the heated surface. At that temperature the iron or steel has a great affinity for oxygen; so the metal is oxidized or burned up so rapidly that a clean cut is made in the piece. The metal is entirely destroyed, of course, but the work is done so quickly and the slot cut is so narrow that it is considered no disadvantage. The metal passes off in the form of an oxide. Pieces of almost any commercial thickness may be cut and blast-furnace tap holes have been cut out to depths of 4 feet of metal.

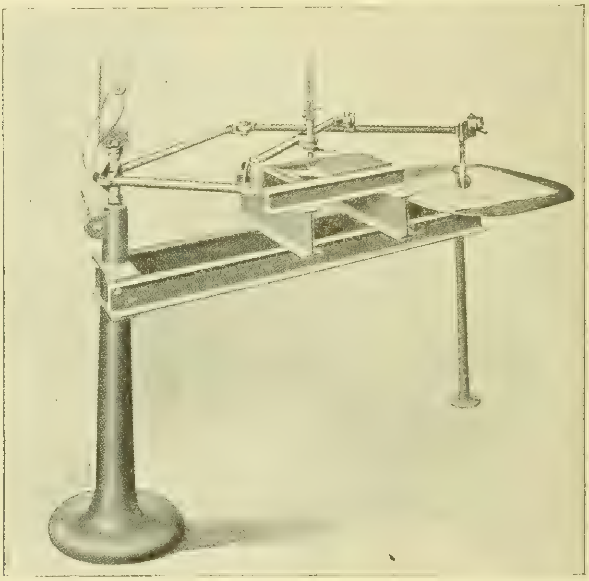


Fig. 124. Oxygraph for Cutting Steel According to Pattern with Oxy-Acetylene Flame
Courtesy of Davis-Bournonville Company

Equipment for Cutting. The apparatus required for cutting consists merely of a torch, Fig. 121, tubes for the gas and oxygen, and a source of supply of gases. The gases are generally supplied in tubes as for welding, and portable outfits are most convenient for all-around use. The torches used for cutting differ from those used for welding in that an extra stream of oxygen must be carried to the tip end, and this is generally done by an extra tube along one side of the torch. In some forms the oxygen is then carried through the preheating flame, but the most efficient types are those in which the oxygen is brought into contact with the metal just back of the main flame and so directed as to cause the oxygen to strike the hot spot. The composition or hardness of the metal have no apparent effect on the speed of cutting and chrome nickel steel armor plates 9 inches thick can be cut at the rate of $2\frac{1}{4}$ minutes per foot of cut, with oxy-hydrogen flames. Figs. 122 and 123 show heavy pieces which have been cut with hot-flame apparatus. Numerous cutting machines have been devised for automatic work, among which are those for holes, rails, cams, irregular curves, and straight lines, Fig. 124, and they are much more rapid and efficient than

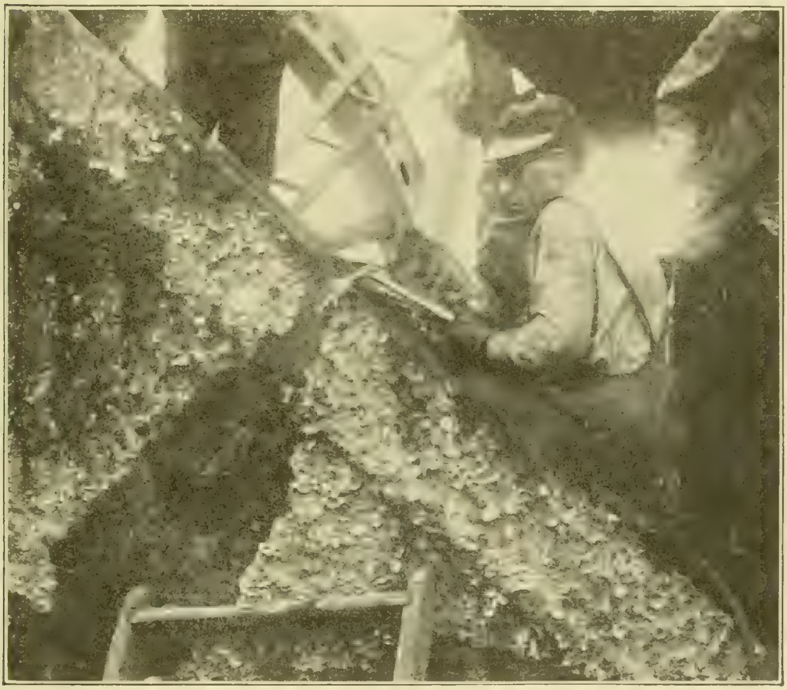


Fig. 125. Cutting up the *Maine* with Gas Blowpipe
Courtesy of Oxweld Acetylene Company

hand cutting because of their uniform feed and speed. For work on which they can be used they are a good investment.

Applications of Hot-Flame Cutting. The applications of hot-flame cutting are so numerous that only a few of them need be described in order to give a good general idea of its possibilities. The accompanying examples were done with oxy-acetylene, oxy-hydrogen, and other gases and the work is very similar with all of them. The principal characteristic of the work done is the smoothness of the cut, and the cost compares very favorably with that of cutting with the electric arc. It is cheaper than the arc on moderate and small work but more expensive on large work. The low first cost of the outfit makes it appeal to small shops and scrap dealers, although it is very valuable for cutting up junk and all sorts of wreckage. The battleship *Maine* was dismantled with an Oxweld acetylene outfit, Fig. 125, and the ruins of the Quebec bridge were also cut away with this apparatus, Fig. 126. Manholes in tanks and boilers, portholes in steel vessels, ruins of burned or wrecked build-

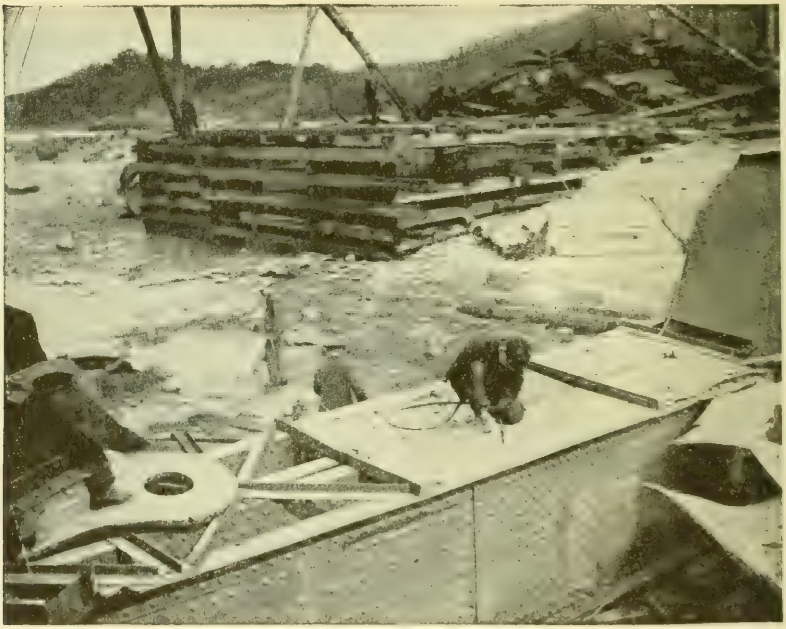


Fig. 126. Cutting up Ruins of Quebec Bridge with Acetylene Blowpipe
Courtesy of Oxweld Acetylene Company

TABLE XV

Cost of Cutting per Foot of Cutting Length

Thickness of iron in inches	$\frac{1}{8}$ in.	$\frac{1}{4}$ in.	$\frac{5}{16}$ in.	$\frac{3}{8}$ in.	$\frac{1}{2}$ in.	$\frac{5}{8}$ in.	$\frac{3}{4}$ in.	1 in.	$1\frac{1}{4}$ in.	$1\frac{1}{2}$ in.	2 in.
Cunsumption of oxygen in cubic feet per foot of cutting length	0.45	0.50	0.60	0.90	1.30	1.90	2.50	3.10	4.00	5.60	7.60
Consumption of acetylene in cubic feet per foot of cutting length	0.12	0.13	0.13	0.18	0.19	0.21	0.25	0.30	0.36	0.41	0.47
Length of time in minutes per foot of cutting length	1	1	1	$1\frac{1}{4}$	$1\frac{1}{4}$	$1\frac{1}{3}$	$1\frac{1}{3}$	$1\frac{1}{3}$	$1\frac{1}{2}$	$1\frac{1}{2}$	$1\frac{3}{4}$
Total cost in cents per foot of cutting length	1.25	1.35	1.5	2.1	2.7	3.7	4.6	5.7	7	9.5	12.75
Thickness of iron in inches	$2\frac{1}{2}$ in.	3 in.	4 in.	5 in.	6 in.	7 in.	8 in.	9 in.	10 in.	11 in.	12 in.
Consumption of oxygen in cubic feet per foot of cutting length	8.25	11.80	15.30	20.60	26.00	32.00	37.00	44.00	51.00	59.00	68.00
Consumption of acetylene in cubic feet per foot of cutting length	0.60	0.90	1.20	1.40	1.65	1.90	2.10	2.35	2.70	3.10	3.25
Length of time in minutes per foot of cutting length	2	$2\frac{1}{2}$	3	3	$3\frac{1}{2}$	4	4	5	5	$5\frac{1}{2}$	6
Total cost in cents per foot of cutting length	14.5	20	25	34	42	52	59	71	82	95	108

This table is based on a price of $1.50 for 100 cubic feet of oxygen, of $3\frac{1}{2}$ cents per lb. for the calcium carbide and on an expense for wages of 35 cents per hour. The figures relating to the consumption of material are but approximate and are supposed to be for straight cutting. The necessary proficiency and experience can be acquired in a few days.

ings, and, in fact, almost anything of metal may be cut by this process rapidly and conveniently. It is not necessary to have the article in any particular position as the work may be done wherever the operator can carry his torch. Work has been done on the top of high towers and stacks and down in deep holes and in steam vessels, inside locomotives, and on the lower side of bridges.

The cost of cutting steel pieces, per foot of length, using the oxy-acetylene flame is given in Table XV by Messer and Company, Philadelphia, and is approximately correct for other systems.

Cost of Hot-Flame Cutting. The cost of cutting will depend upon the cost of the gases, cost of labor, the nature of the work, and the facilities for handling it, but a few typical jobs will give a good idea of the possibilities. The accompanying connecting rod forging for a stationary engine is 6 inches thick and the crosshead slots are each $9\frac{1}{2}$ inches by 7 inches in size and were cut out in 15 minutes each. The total cost of the operations was $6.00, including labor and gas; whereas the usual method of drilling and chipping would have taken 8 hours for each slot and have cost more. In steel and iron foundries this system is used for cutting off risers and gates from the castings and, in boiler shops, for cutting plates of considerable thickness, cutting off rivet heads, cutting holes, etc. The 4×6 foot plate, $\frac{9}{16}$ inch thick, shown in one of the illustrations is a cross brace plate for a locomotive frame and was cut as shown in one hour. The total amount of cutting was 264 lineal inches, which is at the rate of $3\frac{3}{4}$ minutes per running foot. Where articles are to be welded after cutting, it is necessary to remove the oxidized surface from the cut before welding. This can be done with a pneumatic chisel.

THERMIT WELDING

Welding by the thermit process is really "cast welding", because it is accomplished by pouring "thermit steel" around the parts to be joined. The main difference between this and other methods of cast welding lies in the method of producing the molten metal. The name for the process is derived from the Greek word *therme*, meaning "heat", and signifies that it is a heat process of welding or that the metal is produced by heat. The name was originally adopted as a sort of trade-mark but has come to be accepted as the name of the process.

Chemical Reactions in Thermit Welding. The thermit welding process is based upon a long series of experiments carried on for a number of years by various physicists and metallurgists to find some method of reducing metals readily from their oxides and ores. It is the direct result of the work done by Dr. Goldschmidt, of Essen, Germany, in what is now the new field of aluminothermics, and is based on his discovery that if finely divided metallic oxides are mixed in certain proportions with finely divided aluminum they will, if ignited, fuse and produce a temperature of 5400 degrees Fahrenheit in less than 30 seconds without the use of heat or power from the outside. The high affinity of aluminum for oxygen will cause it to draw the oxygen from the metallic oxide, combine with it to form aluminum oxide, raise the temperature of the mass by the violent reaction, and set the metal free. The greater weight of the metal will cause it to flow down through the mass in the container and the aluminum slag will rise to the top.

For ordinary commercial welding purposes in machine shops and foundries, iron oxide is used and the reaction takes place according to the equation.

$$Fe_2O_3+2Al=2Fe+Al_2O_3$$

The liquid steel produced by this process represents one third of the original material by volume and one half of the original mixture by weight, the balance being lost as slag. This method of cast welding was developed about the year 1900 and the peculiar reaction used has also been applied to the production of numerous kinds of alloys and metals free from carbon. Further reference will be made to this.

Analysis of the Composition of Thermit Steel. According to data furnished by the makers of thermit welding apparatus the average analysis of thermit steel is as follows:

Carbon	0.05 to 0.10
Manganese	0.08 to 0.10
Silicon	0.09 to 0.20
Sulphur	0.03 to 0.04
Phosphorus	0.04 to 0.05
Aluminum	0.07 to 0.18
	0.36 to 0.67

The balance of the mixture is iron.

Method of Starting the Reaction. During the experiments leading to the development of thermit welding, the mixture of metallic oxide and aluminum was heated from the outside to start the reaction, but finely divided aluminum will not melt at the temperature of cast iron and it was necessary to heat the mass so high that when action started it resulted in an explosion. So Dr. Goldschmidt used a storm match to ignite a fuse of barium peroxide, (BaO) which in turn ignited the mixture and started the reaction.

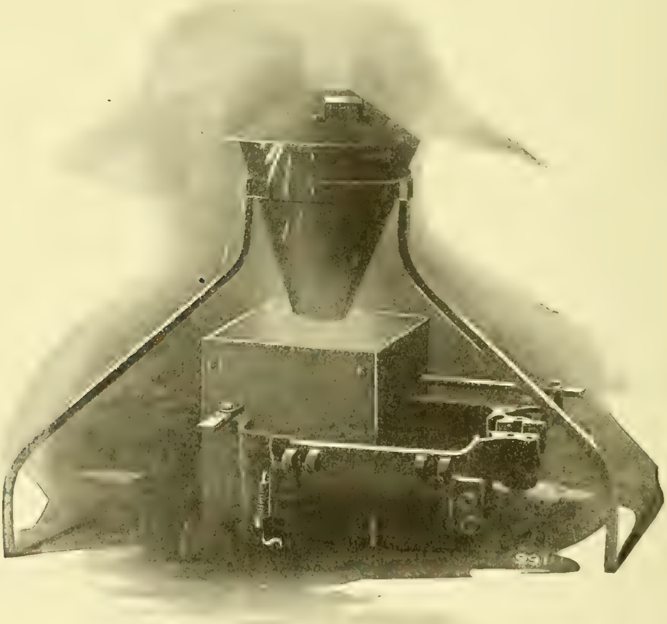


Fig. 127. Thermit Crucible Pouring Charge into Mold
Courtesy of Goldschmidt Thermit Company

Equipment for the Process. The apparatus required for thermit welding consists of a crucible, tripod, preheater, yellow wax, and a spade, with which there must also be used perishable materials consisting of thermit, manganese, molding material, and ignition powder. The shell of the crucible is of sheet iron and it is lined with magnesia in order to stand the high temperature and has a magnesia stone thimble at the bottom through which the metal flows. The process of preparing the lining is rather elaborate and must be carefully done or the life of the crucible will be greatly reduced. The tripod is used to support the crucible above the work, and the preheater is a combination compressed air and gasoline outfit used to heat the article to be welded in order that it may not chill the filling material. The wax is for forming the space to be filled when welding and about which a mold is made. It is melted out of the mold before welding.

Preparing the Mold. The process of preparing the crucible and the mold are the principal features of the entire operation of thermit welding, as the mere act of casting the weld is comparatively simple. The crucible, which is shown in Fig. 127, suspended above the mold, is a sheet-iron shell with a hole below for the metal to pass through. It is to be lined with magnesia, carefully packed while hot enough to be plastic, and with a magnesia stone thimble at the bottom to form a bushed hole and protect the crucible. The magnesia lining should be put into place slowly and carefully and tamped tightly into place, for its value depends largely upon how hard it is packed. The lining is formed around a matrix to shape the hopper-like center and must be baked at a dull red heat for six hours before it is ready to use. A crucible will withstand about 20 reactions if well made, and must then be relined. The thimble must be placed in the bottom of the crucible so as to be removable.

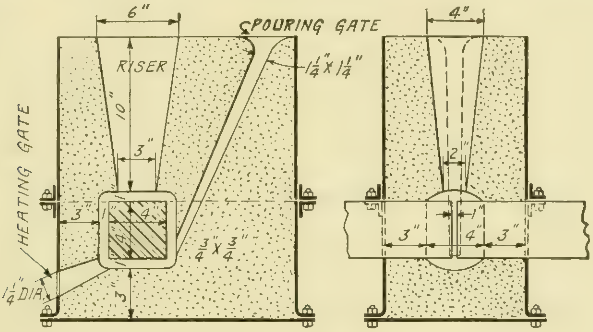


Fig. 128. Section of Typical Thermit Mold Showing Riser, Pouring Gate, and Heating Gate
Courtesy of Goldschmidt Thermit Company

Construction of Mold. The construction of the mold is really the most important part of the operation, because upon this depends the amount and application of the filling material. The container or flask is usually made of steel plates placed so as to form a box around the part to be welded, and then filled with the clay, etc., of the mold, the plates being fastened with bolts, tie-rods, clips, or clamps of whatever sort may be available, Fig. 128. The first step in the formation of the mold is to build a collar of the yellow beeswax around the place to be welded, making this of the size and shape desired for the weld. After the collar is formed, the flask is placed around it and filled with a mixture of ground fire brick, fire clay, and fire sand in equal parts. There must be three channels in every mold, a pouring gate, a riser, and a heating gate. The pouring gate should run from the top of the mold down to the bottom of the wax collar to insure the metal filling the mold and to allow the good steel to reach the weld instead of being crowded out by the slag. The riser should be immediately above the wax collar, if possible, so that the slag and surplus metal can rise freely from the metal of the weld, and the heating gate should run from one side of the mold into the bottom of the collar in order that the wax can

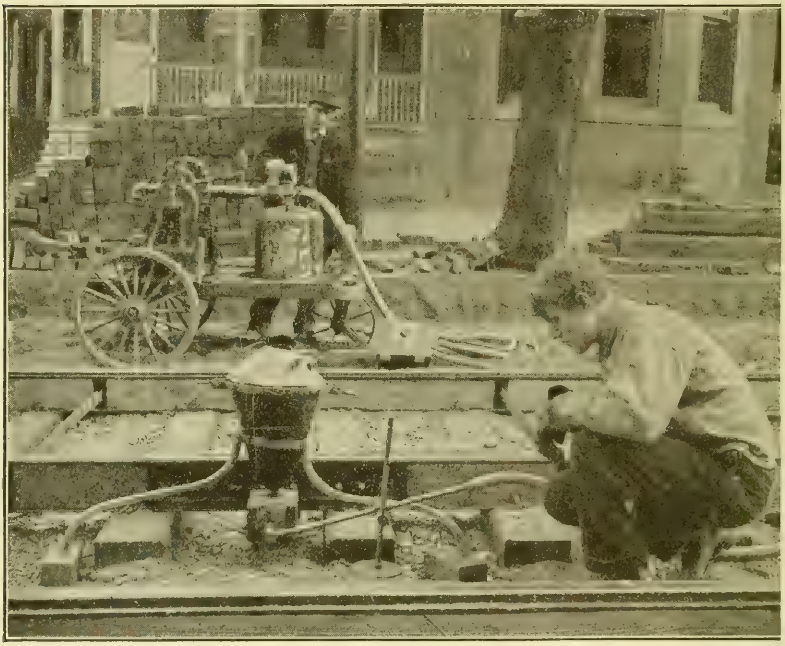


Fig. 129. Preheating Steel Rail Prior to Forming Weld
Courtesy of Goldschmidt Thermit Company

all run out of the mold when melted by the preheating torch. As soon as the mold is completed, the torch is applied and the wax melted out, Fig. 129. The flame is allowed to play into the mold until it is entirely dry and then the heating gate must be plugged with clay to stop it up entirely. Fig. 130 shows a typical thermit weld, with pouring gate and riser still attached.

Thermit Required for a Given Weld. The amount of thermit required to make a given weld will be twice the amount necessary to fill the space formed by the wax collar, because one-half of the weight of the original powder will rise in the form of aluminum slag, as already stated. On the other hand, the cubical area of riser and gate must be twice as great as the collar because the volume of the slag will be two-thirds of the total volume of the casting. It has been determined by experience that the weight of thermit necessary for a given job will be 32 times the weight of the wax required to form the collar for the mold; so the wax should be weighed after melting out of the mold in order to know how much thermit is required for the job. The size and shape of the mold and riser and gate will vary somewhat for different jobs and the relation between weight of wax and mixture will vary accordingly, but the ratio of 32 to 1 is a good average. It is necessary to preheat the article at the joint until it is red-hot before starting to pour the metal, and this is done with the gasoline torch through the heating gate at the bottom of the mold before plugging it.

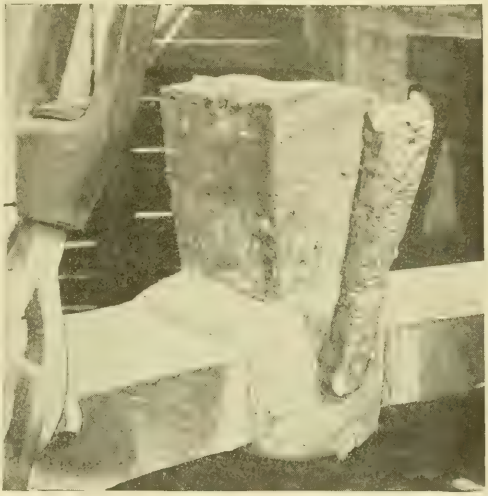


Fig. 130. Typical Thermit Weld Showing Riser and Pouring Gate Casting Still Attached
Courtesy of Goldschmidt Thermit Company

Addition of Other Materials. When more than 10 pounds of thermit are required for the weld, it is necessary to moderate the heat of the reaction slightly, and this is done by adding small pieces of clean steel to the powder. These may be punchings, rivets, or any other soft steel pieces but must be free from grease to keep carbon out of the mixture, and from 10 to 15 per cent of the weight of the thermit may be added in this way. About 2 per cent of pure metallic manganese should also be added in order to increase the strength of the weld. If the manganese is not obtainable, 3 per cent of ferromanganese may be added instead, although it increases the violence of the reaction and hardens the metal.

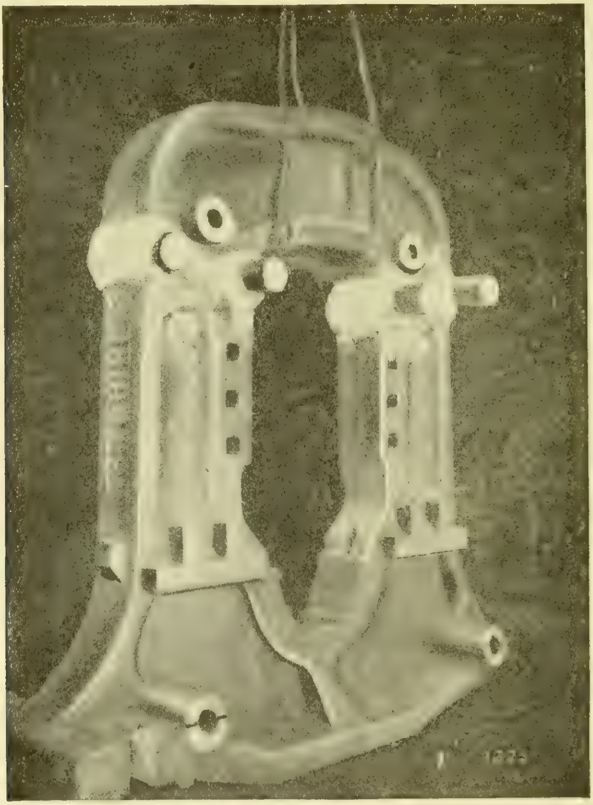


Fig. 131. Rolling Mill Housing Welded by Thermit Process
Courtesy of Goldschmidt Thermit Company

Strength of the Weld. The average tensile strength of the welds made with thermit are 30 tons per square inch of cross section and, if the joint is properly made, it will be hard to see where it is.

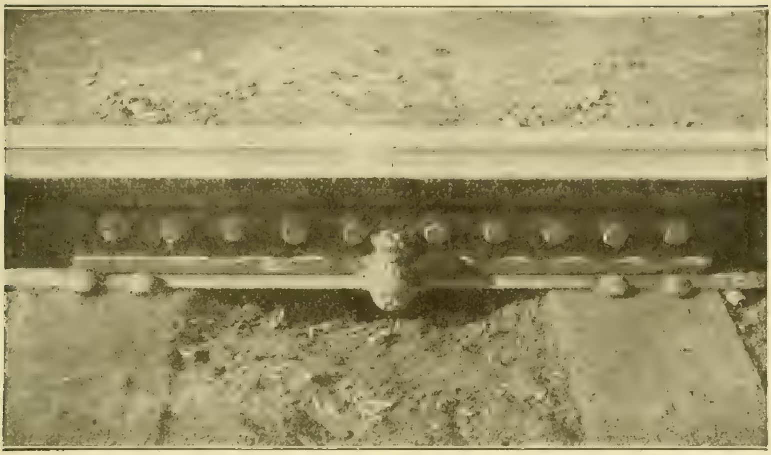


Fig. 132. Rails Welded by Thermit Process
Courtesy of Goldschmidt Thermit Company

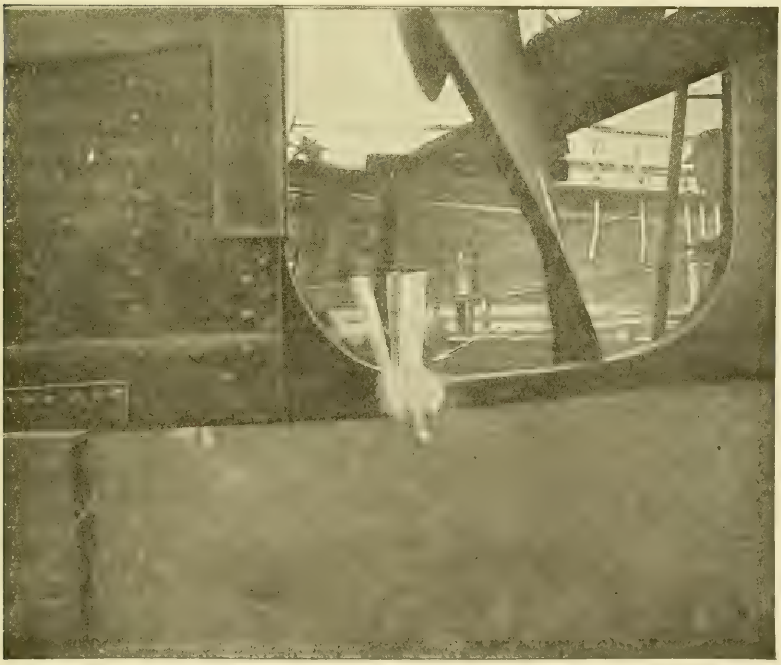


Fig. 133. Broken Stern Post of Boat Welded by Thermit Process
Courtesy of Goldschmidt Thermit Company

If a reinforcement can be left around the weld, it will give a higher strength than the original material, but where it is machined off the strength will average 80 per cent of that of the piece welded unless it be of unusually high tensile strength. When preparing the joint for welding, it is best to leave an opening for the metal to flow into, and this should be at least $\frac{3}{4}$ inch wide, preferably more.

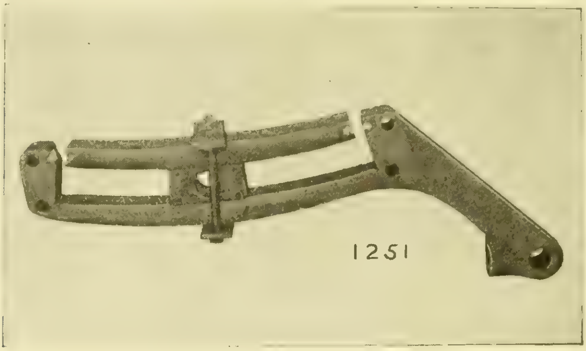


Fig. 134. Broken Locomotive Link Ready for the Molds
Courtesy of Goldschmidt Thermit Company

Applications of Thermit Welding. The applications of thermit welding are numerous, although the process is better suited to large jobs where the saving in cost of new pieces will justify the cost of the work, Fig. 131. It will be evident also that the process lends itself better to welding large articles than small ones and experience up to the present shows that most thermit welding has been done

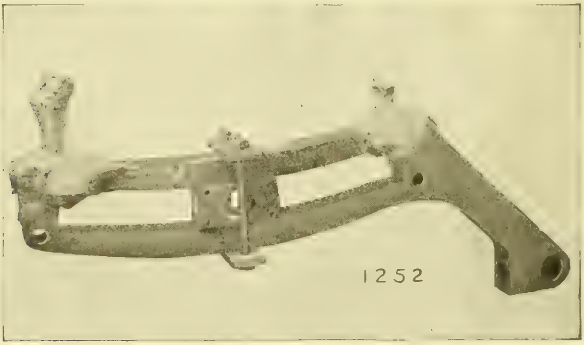


Fig. 135. Welded Locomotive Link with Molds Removed
Courtesy of Goldschmidt Thermit Company

on such large articles as engine and machine tool frames, locomotive side frames, and motor cases. Fig. 132 shows a typical thermit weld at a rail joint. This is a modified Clark joint. Another useful application of the method is in welding stern posts and rudder posts of vessels, Fig. 133. The widest application seems to be in steam railroad shops and, while it is true that the electric arc-welding process is rapidly superseding all others for that service, some of the work done is worthy of description. Considerable saving has been made by doing the work without dismantling the engines in order to get at the break. The process is to form the mold about the break, as described, and set the crucible above it ready for pouring. Where it is possible to lay the article on the floor, as when welding crank shafts or a broken link, Figs. 134 and 135, the job is much easier and quicker to perform.

If the break is in the upper part of a locomotive frame, for example, the break should be cut out about an inch and the frame jacked apart another quarter of an inch. The inch space is for filling and the $\frac{1}{4}$ inch is to allow for shrinkage; so the jacks should be removed as soon as the mold is filled. Breaks in other parts of locomotive frames are treated in the same way. For welding driving-wheel spokes, it is best to heat the adjacent spokes with a torch to expand before welding the broken ones, and then allow them all to cool at once. Rail welding for street railways is another application of thermit and is clearly shown by the cuts herewith, In all cases it is necessary to clean the metal thoroughly around the joint to remove grease and scale, and this is best done with a sand blast so as to insure bright clean metal to fill against. For work of this nature it pays to provide the fullest equipment in order that there may be no failures, because it is a very expensive operation and very hard to do over again.

Use of Thermit in Other Processes. *Foundry Work.* Other uses of thermit are in foundries for improving the quality of the castings and in metallurgical work to produce metals and alloys free from carbon. In foundries it has been found that, by placing a can of thermit in the ladle before pouring, the temperature of the metal will be raised and, by using thermit of the proper composition, the strength of the metal can be increased or its composition varied to suit different jobs. It is also used in steel mills to reduce losses from "piping" of the ingots. A pipe is a hole formed in the top of the ingot when cooling, due to shrinkage and the presence of slag, and it may extend a considerable distance down into the ingot and reduce its value for rolling. So a can of thermit is thrust down into the top of the ingot at a certain point in the cooling, and this ignites and fuses the steel down and forces the slag out. The mold can then be filled the rest of the way with good steel.

Producing Alloys. The use of thermit, for the production of alloys, etc., has been successful with such metals as titanium, chromium, manganese, vanadium, etc., and alloys of the following compositions have been made.

Ferrotitanium	20–25 % Ti.
Chromium	97–98 % Cr.
Chromium Manganese	30–70 parts
Chromium Copper	10 % Cr.
Chromium Molybdenum	50–50 parts
Manganese	97–98 % Mn.
Manganese Copper	30–70 parts
Manganese Titanium	30–35 % Ti.
Manganese Tin	50–50 parts
Manganese Zinc	20–80 parts
Manganese Boron	30–35 % Bo.
Ferrovanadium	30–35 % Va.
Ferromolybdenum	50–50 parts
Ferroboron	20–25 % Bo.

Ferrotitanium is used as a purifying agent for steel; chromium is used as an alloy with steel to produce crucible steel, etc.; manganese is used to produce very hard steel, bronze alloys, etc.; molybdenum is used in making tool steels; vanadium is used to add to the strength of iron and steel.

GLOSSARY

GLOSSARY

THE following glossary of electrical terms is not intended in any sense as an electrical dictionary and only words used in the articles themselves have been defined. The definitions have been made as simple as possible, but if other electrical terms unfamiliar to the reader are used these also should be looked up in order to obtain the complete definition. In cases where a short definition of a term or a device has seemed impossible, reference has been made to the volume and folio, where a complete analysis or description of the term may be found:

A: A prefix meaning "not", hence equivalent to "non", e.g., aperiodic = without a period; asynchronous = not synchronous.

Abscissa: A distance measured along the axis of abscissas. See "ordinate".

Absolute Measurement: A measurement in which all the factors entering into the final result are directly measured in terms of the three fundamental units.

Absolute Units: The fundamental units (q.v.).

Accumulator: (See Storage Battery.)

Admittance: The admittance of an alternating current is the number of amperes of current per volt applied to the circuit. The unit is the ohm.

Aerial: A wire or group of wires supported above the ground and used for transmitting or receiving energy by electrical waves in the ether.

Algebraic: That is, taking account of plus or minus signs, e.g., algebraic sum.

All-Day-Efficiency: The total output divided by the total input of energy for the entire day.

Alloy: An intimate mixture of two or more different metals.

Alternator: A dynamo-electric machine in which no commutation takes place, therefore carrying a current alternating in its direction, v. IV, p. 11.

Aluminum Cell Arrester: v. IV, p. 475.

Aluminum Valve Rectifier: v. IV, p. 334.

Ammeter: An instrument for measuring electrical currents in amperes, v. I, p. 43.

Ampere: The practical unit of current. It is the current which in one second in flowing through a solution of silver nitrate will deposit .001118 gram of silver, v. I, p. 82.

Ampere Hour: A convenient unit of quantity of electricity equal to 3600 coulombs, v. I, p. 113.

Ampere Turns: That magnetomotive force which results from one turn of wire carrying one ampere, v. II, p. 23.

Amplitude Factor: In any wave plot, the ratio of the maximum ordinate to the root mean square ordinate.

Amyl Acetate Lamp: v. III, p. 373.

Angular Velocity: The rate of angular separation, usually measured in radians per second.

Anion: The ion which moves toward the anode.

Anode: The positive terminal in a vacuum tube or electrolytic cell.

Antennae: "Feelers" like those of insects. More particularly, the wires similar in appearance which constitute an aerial in wireless telegraphy.

Anti-Parallel: A method of arranging the wires in a system of distribution of electrical energy to loads in parallel so that the voltage regulation at every load will be approximately the same, v. III, p. 319.

Apparent Efficiency: In alternating-current apparatus the ratio of net power output to "volt-ampere" input.

Apparent Watts: The volt-amperes of an alternating-current machine.

Arc: A passage of electricity between two conductors through the air space separating them, accompanied by heat and light, and hence the basis of arc lamps or furnaces.

Arc Furnace: A furnace used in electrochemical processes where the heat is obtained from an electric arc.

Arc Lamps: v. III, p. 295 and following.

Arithmetical: Without regard to signs, e.g., arithmetical sum.

Armature: That coil of a dynamo-electric machine which carries the useful current as distinct from those coils which carry the current which excites (i.e., establishes) the magnetic field, v. II, p. 37.

Armature Back-Ampere-Turns: The measure of the demagnetizing force of the armature current, v. II, p. 65.

Armature Core: The iron portion of an armature which forms part of the magnetic circuit of a dynamo-electric machine, v. II, p. 43.

Armature Cross-Ampere-Turns: The measure of the force producing cross magnetization (q.v.), v. II, p. 64.

Armature Demagnetization: The demagnetizing force exerted upon the magnetic path through the armature of a generator by the armature current when the brushes have a forward lead. For a motor this occurs for a backward lead of the brushes.

Arrester: A device for protecting electrical apparatus from high potential surges of current such as those due to lightning, v. IV, p. 470.

Astatic System: An arrangement of two parallel magnets with the north end of one pointing the same way as the south end of the other so that the two together make a very inefficient compass needle, v. I, p. 308.

Asynchronous Generator: An induction generator, v. IV, p. 415.

Atomic Weight: The weight of one atom of a chemical element in terms of the weight of one atom of some element taken as a standard, e.g., hydrogen as unity.

Autostarter: An arrangement of autotransformers whereby an induction motor can be started on low voltage and later be connected to the full voltage, v. IV, p. 405.

Autotransformer: A connection of the two coils of a transformer whereby part of the energy received is transmitted directly by conduction and part by induction or true transformer actions, v. IV, p. 265.

Axis of Commutation: The line connecting brushes bearing on the commutator of a dynamo-electric machine.

Ayrton Shunt: A scheme of resistances whereby any desired fraction of a given current can be passed through a measuring instrument across whose terminals this shunt is connected.

Balanced System: An electrical system, either d.c. or a.c., for distributing energy by means of three or more wires in which each generator if d.c. or each phase if a.c. supplies the same power. To obtain this the loads must be equal and symmetrically connected to the supply wires.

Ballistic Galvanometer: A type of galvanometer used for measuring the quantity of electricity suddenly discharged through it, say from a condenser, in terms of the sudden swing which is thus given to the movable part of the instrument, v. I, p. 312.

Barrel Winding: A type of drum armature winding, v. II, p. 186.

Battery: A cell or jar containing substances such that by chemical action electrical charges are produced. (See Storage Battery, Dry Battery, etc.)

Bi: A prefix meaning "two", e.g., bipolar.

British Units: (See **F. P. S. Units.**)

Bond: The short high-grade conduction used to connect two rails in an electric traction system where the rails are a return circuit for the electric current.

Booster: A machine inserted in a circuit to change its voltage, v. VI, pp. 267-273.

Bridge Duplex: A duplex telegraph system dependent for its operation upon the use of a Wheatstone bridge connection in which the telegraph circuit and an artificial line similar to it are two arms, v. VII, p. 45.

Busbar: The prefix bus means "for several things"; hence a busbar is a bar of conducting material for connecting electrically several pieces of apparatus. It is mounted on a "switchboard" usually.

Cadmium Test: A test using a cadmium electrode for determining the potentials of the electrodes of a storage battery, v. VI, p. 234.

Calorie: A unit of heat (which is a form of energy) representing the heat required to raise one gram of water 1° centigrade. 1 calorie $=4.2$ joules, approximately.

Candle: A unit in which is measured the amount of luminous energy given off by any source, v. III, p. 372.

Capacity: The measure of the ability of a condenser to hold electricity. (See Farad.)

Capacity Reactance: The measure of the opposition to the passage of an alternating current through a condenser is given in ohms as $\frac{1}{2\pi f c}$ where c is the capacity in farads and f is the frequency in cycles per second.

Carcel Lamps: v. III, p. 373.

Cascade: (See Concatenation.)

Catenary: The curve formed by a perfectly flexible wire supported at its ends and acted upon by gravity.

Cathion: The ion which moves toward the cathode.

Cathode: The negative terminal of a vacuum tube or electrolytic cell.

Central Station: When many different users of electricity are supplied from a single power plant, this is usually termed a central station. Separate plants for each user are called "isolated", v. I, p. 118.

Centrifugal Force: A force with which a body caused to move along a curved line tends to fly outward. The force required to balance the centrifugal force is called "centripetal".

C. G. S. Units: A system of units universally used in electrical measurements in which the fundamental units are, one of length, the centimeter; one of mass, the gram; and one of time, the second, v. I, p. 297.

Characteristic: A plot giving the relation between any two variables in the operation of a dynamo-electric machine, e.g., load current and external e.m.f. for a generator, v. II, p. 154.

Chloride Cell: v. VI, p. 219.

Choke Coil: A coil having high inductance whose function in a circuit is to oppose any cause acting to produce a sudden change in the current through it.

Chord Winding: A scheme of connection for inductors in an armature winding in which the winding pitch is less than the pole pitch, v. II, p. 115.

Circular Mil: A convenient unit of area for circles representing the area of a circle 1 mil in diameter. (See Mil.)

Clark Cell: A primary battery used as a standard of e.m.f., v. I, p. 298.

Clock Diagram: A representation of electrical quantities in alternating-current work by vectors drawn from a common point, like the positions of the hands of a clock.

Coefficient of Magnetic Leakage: The ratio between the total flux produced by the field coils of a dynamo-electric machine and the useful flux. (See "Magnetic Leakage".)

Coercive Force: That reverse field required to reduce to zero the residual induction, which is known as "retentiveness."

Coherer: A detector (q.v.) in which the cohesion of small particles of metal caused by weak high frequency currents produces sufficient change of resistance to be observable in a second circuit, v. VII, p. 118.

Collector Ring: A ring connected to a rotating armature with which continuous contact can be made by a fixed conductor (a brush) and from which the current may pass in or out of the armature, v. II, p. 39.

Commercial Efficiency: The ratio of total output to total input of power. (See Apparent Efficiency, Efficiency of Conversion, and Electrical Efficiency.)

Commutator: A device for changing (reversing) two pairs of contacts, e.g., connecting first wire *a* to wire *b* and wire *c* to wire *d* and then interchanging to connect wire *a* to wire *d* and wire *c* to wire *b*, v. II, p. 36.

Compensator: A name that is applied to any device which offsets or equalizes in its effect some undesired effect, e.g., a starting compensator for a motor prevents a sudden rush of current.

Component: Any vector may be considered to be the resultant of two vectors known as its components. The size of these component vectors and the direction of one of them are dependent upon the given vector; the direction of the other component may be chosen as desired.

Composite: A name descriptive of a circuit arranged for the simultaneous transmission of a telephone message and one or more telegraphic messages.

Compound Generator (or Motor): One where there are two different sets of field coils, one set connected in series with the armature and the other set in parallel with the armature. (See Short Compounding and also Long Compounding.)

Compressive Strength: A measure of the force per unit of cross-sectional area required to crush a given material.

Concatenation: A tandem connection, electrically, of two induction motors attached to the same shaft whereby a speed reduction is obtained similar to that when two d.c. motors on the same shaft are connected in series. Also called "Cascade". Concatenation is accomplished when the rotor of one motor supplies the current for the stator of the second motor.

Condenser: An arrangement consisting of two conductors separated by a non-conductor which thereby has the ability of holding equal but unlike charges of electricity upon the two conductors, v. I, p. 34.

Conductance: When a conductor has no inductance, or for steady currents, the conductance of a conductor is the reciprocal of its resistance. When a conductor has inductance and is carrying an alternating current, its conductance is

$$\frac{r}{r^2 + x^2}$$

where r is its resistance and x is its reactance. (See Reactance.)

Conductivity: The measure of the ability of a substance to transmit electricity. It is the reciprocal of the specific resistance of a substance, v. I, p. 85.

Conductor: A body possessing the ability of transmitting electrical charges, i.e., of carrying an electric current.

Conduit: A pipe or parallel group of pipes used for carrying electrical wires underground. (See Duct.)

Contact Resistance: The resistance across the contact or joint when two conductors, e.g., a rail and a bond, are joined together.

Contact Series: Two dissimilar metals in contact have a difference of potential across the contact. If a list of metals is so arranged that each metal is positive when in contact with the next metal on the list, then this list is a contact series.

Control: Control of a machine is due to human actions. Regulation is inherent in the machine depending only upon its design, can be foretold, and is entirely automatic.

Controller: A general term for the device by which the running conditions of a motor may be varied.

Cooper-Hewitt Mercury Vapor Lamp: v. III, p. —.

Copper Losses: Losses due to resistance and skin effect in the windings of dynamo-electric machines.

Core-Type Transformer: v. IV, p. 284.

Cosine: The cosine of an acute angle (e.g., θ), written "cos θ" is the ratio in any right-angle triangle constructed on this angle of the length of the side adjacent to the angle θ to the length of the hypothenuse of the triangle.

Coulomb: The practical unit of quantity of electricity. It is that quantity which is passed by a current of 1 ampere flowing for 1 second, v. I, p. 113.

Coulomb's Law: A statement that the force exerted between two charged bodies (or magnets) is proportional to the product of the charges (or magnet pole strengths) and inversely as the square of the distance between the charges (or magnet poles), v. II, p. 16.

Coupling: Connecting by mutual inductance.

Cross-Magnetization: When the brushes on the commutator of a dynamo-electric machine are not placed along the neutral line, the current in the armature produces a magnetic field having a component at right angles to the field produced by the field coils, v. II, p. 64.

Cumulative: Having to do with the sum of two effects, as a cumulative compound motor connection where the effects of two fields add to give a net effect greater than that of either.

Current: Electricity in motion. An electrical current is due to the movement of electrons. It is measured by the quantity of electricity which flows per second, v. I, p. 38. (See Ampere.)

Current Transformer: A transformer to be inserted in series in a circuit and to connect inductively with a current measuring instrument.

Cut-Out: A circuit breaker or switch which automatically operates under given conditions to open the circuit in which it is placed.

Cycle: A complete set of values of some variable such that the last value of the set is the same as the first and the set is then ready to be repeated, v. IV, p. 13.

Damping Ring: (See Magnetic Damper.)

Dashpot: A cylinder closed at one end and fitted loosely by a piston, the sudden motion of which is retarded by the contents of the cylinder (air or oil).

D'Arsonval Galvanometer: A type of galvanometer where a coil carrying the current to be measured is free to turn in a magnetic field, v. I, p. 311.

Deceleration: Negative acceleration, i.e., rate of decrease of velocity.

Delta (Δ): A scheme of connection in three-phase systems, v. IV, p. 135.

Derived Units: Units obtained from the fundamental units, e.g., 1 sq. ft. is a unit of area derived from a fundamental unit of length, namely, 1 ft., v. I, p. 298. (See Fundamental Units.)

Detector: A device for indicating the existence in a circuit (e.g., a wireless telegraph receiving circuit) of a small current of high frequency.

A device associated with a wireless aerial by means of which the received energy may be recognized. This recognition is usually accomplished by associating the detector with some indicating device, e.g., a telephone receiver, in a secondary circuit, v. VII, p. 151.

Dia-Magnetic: Possessing properties opposite to para-magnetic bodies. Dia-magnetic bodies, if free to turn, place themselves crosswise in a magnetic field.

Dielectric Hysteresis: The cause of a power consumption when an a.c. potential is applied to a condenser, v. IV, p. 51.

Dielectric Strength: A measure of the ability of an insulating material to resist breakdown or puncture when subjected to a difference of electrical potential.

Differential: Having to do with the difference of two effects as distinct from "cumulative" (q.v.).

Diffusion of Light: The phenomenon of the apparent bending of light rays around corners which takes place when the rays pass through very small openings or are intercepted by very small particles, e.g., dust particles or moisture in the air, whereby a general illumination from a single source like the sun is made possible.

Diplex: (See Duplex.)

Disk Armature: v. II, p. 43.

Disk-Type Insulator: v. V, p. 296.

Dispersion: (See Coefficient of Magnetic Leakage.)

Dissociation: The phenomenon of the splitting up of a molecule into two parts, one positively charged and the other equally and negatively charged, which takes place when salts, acids, or bases are in solution. Dissociation is the cause of electrolysis, v. I, p, 49.

Divided Circuits: Parallel circuits are sometimes called "divided circuits".

Drum Armature: v. II, p. 41.

Dry Battery: A primary cell of the Leclanché type where the ammonium chloride is held in a moist paste, v. I, p. 54.

Duct: A passage way in a conduit. A conduit is a system of parallel ducts.

Duplex: A name descriptive of a telegraph system where two messages from opposite directions can be sent simultaneously over a single circuit.

Duplex Winding: A special type of armature winding, v. II, p. 123.

Dynamo: (See Generator.)

Dynamo-Electric Machine: One which converts mechanical energy into electrical energy or *vice versa.* See Generator and Motor, v. II, p. 15.

Dynamo Rule: v. II, p. 22.

Dynamotor: A direct-current machine having two separate commutators to one of which energy is supplied to cause motor action and from the other of which energy is obtained by dynamo action.

Dyne: The unit of force in the C.G.S. system is that force capable, after acting for 1 second on a mass of 1 gram, of giving it a velocity of 1 centimeter per second, v. II, p. 11.

E.M.F.: (See Electromotive Force.)

Eddy Currents: Local currents induced in any magnetic body subjected to a varying magnetizing force. Such currents are not useful and result in local heating and energy losses. The plane of their paths is at right angles to the magnetic field, v. II, p. 31.

Edison Cell: v. VI, p. 226.

Effective Value: The square root of average value of the squares of all the instantaneous value for a complete cycle.

Efficiency: The ratio of the energy output of a machine to its energy input, v. I, p. 119.

Efficiency of Conversion: The ratio of power converted in the armature of a generator (from mechanical power to electrical power) to the power input required to turn the armature.

Electrical Degrees: A complete wave corresponds to the plot of the values for sin θ between $\theta = 0$ and $\theta = 360°$. The cycle for an alternating current or e.m.f. is then said to take place in 360 electrical degrees as distinguished from "space degrees" (q.v.).

Electrical Efficiency: The ratio of the useful electrical power output from the armature of a generator to the total power developed in this armature.

Electrification: The act of producing electrically charged bodies, v. I, p. 20.

Electrodynamometer: An instrument for measuring current (or power) based upon the reaction between the current in two coils, one fixed and the other movable, v. I, p. 319.

Electrochemical Equivalent: The atomic weight of an element or radical in terms of hydrogen divided by its valency and multiplied by the amount of hydrogen liberated by the passage through acidulated water of one c.g.s. unit of electricity.

Electromagnet: A piece of iron around which is wound a wire so that an electric current in the wire makes the iron act like a magnet.

Electrometer: An electroscope calibrated to read potential differences, v. I, p. 327.

Electromotive Force (e.m.f.): The cause of a difference of potential. It is measured in the same units as difference of potential, e.g., volts, v. I, p. 81.

Electrolysis: The phenomenon of the chemical decomposition which takes place when an electric current is passed through a solution containing an acid, a salt, or a base.

Electrolyte: A solution in which a chemical separation takes place upon the passage of a current.

Electrolytic-Cell Arrester: v. IV, p. 474.

Electrolytic Detector: v. VII, p. 159.

Electron: A negatively charged particle ordinarily associated with an atom but free to move and hence serving as the carrier of electricity through conductors, v. I, p. 24.

Electrophorus: A simple device for producing electrification, v. I, p. 36.

Electroplating: An application of electrolysis to the deposition of a metal upon a plate by the passage of a current through a solution of a salt compound of the metal.

Electroscope: An instrument for detecting the presence of an electrical charge upon a body and of determining the sign of that charge, v. I, p. 25.

Electrostatic Induction: The act of producing electrification by the influence of neighboring charged bodies, v. I, p. 23.

Electrostatic Voltmeter: (See Electrometer.)

Electrothermic: Having to do with heat obtained from a source of electrical energy.

Endothermic: A term describing a chemical action which absorbs and requires heat. (See Exothermic.)

Energy: The ability to do work. It is measured in the same units as work, e.g., joules.

Erg: The unit of work in the C.G.S. system is the work due to one dyne of force acting through a distance of one centimeter, v. II, p. 11.

Equalizing Switch: A switch so placed as to connect those points of two or more machines which must be maintained at a common voltage if these machines are to be operated satisfactorily in parallel.

Ether: The name applied to that medium which permeates all space or substances and serves to transmit electromagnetic disturbances.

Evolute Winding: A type of drum armature winding where the conductors are connected to the commutator bars by spiral end-connectors curved like the geometrical figure known as an "evolute", v. II, p. 185.

Excitation: The act of establishing a magnetic field in a dynamo-electric machine.

Exide Cell: v. VI, p. 217.

Exothermic: A term describing a chemical action which gives off heat to its surroundings.

External E.M.F.: Any source of e.m.f. is usually associated with a resistance called its "internal resistance" so that, of the total or internal e.m.f., part is used to overcome the internal resistance, leaving a balance at the terminals known as the "external e.m.f.", v. I, p. 105.

F. P. S. Units: A system of units used in English-speaking countries for mechanical quantities, based upon three fundamental units: one of length, the foot; one of force, the weight of a pound; and one of time, the second.

Farad: The practical unit of capacity is the capacity of a condenser which is charged to potential difference of 1 volt by 1 coulomb, v. II, p. 12.

Faraday's Laws: Faraday's Laws of electrolysis state that the amount of a substance set free from an electrolyte by the passage of a current is equal to the product of the quantity of electricity and the electrochemical equivalent of the substance.

Faure Cell: v. VI, p. 216.

Feeder: Where the loads supplied by the mains of an electrical system are located at some distance apart, the voltage regulation of the system is usually improved by the use of another group of wires, known as "feeders", connecting some point of the mains directly to the generating machine.

Field Coils: Those coils which establish the magnetic field of a dynamo-electric machine.

Field Excitation: (See Excitation.)

Field-Magnets: The iron portion of the magnetic circuit of a dynamo-electric machine, v. II, p. 77.

Field of Force: A region in which a force acts. Mechanical fields of force act on ordinary bodies, magnetic fields of force on magnets, and electrical fields of force on electrical bodies, i.e., charges. A field of force is represented by lines along which the force acts. The strength of a field is measured in units known as "lines of force".

Field Windings: (See Field Coils.)

Filament: The thin conducting wire or thread, the heating of which by the current causes light in so-called incandescent lamps.

Fleming's Rule: v. III, p. 12.

Flicker Photometer: v. III, p. 389.

Flux: The total number of magnetic lines established when a magnetic body (e.g., iron) is placed in a magnetic field. Flux is measured in lines or maxwells, v. II, p. 24.

Flux Density: The number of magnetic lines per square centimeter, v. II, p. 25.

Flux of Light: A measure of the light energy radiating through space which is available at any point to produce illumination, v. III, p. 325.

Foot Candle: A unit in which is measured the illumination due to the available amount of light energy at a given point in a space which receives light radiation from some source, v. III, p. 321.

Foot-Pound: The usual unit of work, representing that required to raise 1 pound 1 foot against the pull of the earth's attraction, v. I, p. 117.

Force: That which produces a change in the state of motion of a body either by moving a body not already in motion or by changing either the speed or direction of motion of a moving body. If a body is at rest under the action of a force, an equal and opposite force is acting on the body.

Form Factor: The ratio of the "effective value" to the average value of a wave. In any wave plot the ratio of the root mean square ordinate to the mean (i.e., average) ordinate.

Foucault Currents: (See Eddy Currents.)

Frequency: Number of cycles per second, v. IV, p. 13.

Frequency Changer: From the rotor terminals of an induction generator can be led off an alternating current of a frequency dependent upon the speed of its rotation and the frequency of the field current.

Friction Brake: A loosely fitting clamp that can be placed around a moving shaft and used to absorb energy in friction and to measure the amount so absorbed, v. III, p. 221.

Frosted: A term applied to lamp bulbs or globes the glass of which has been treated with acid so that it is opaque like "ground glass".

Fundamental Units: By means of relations expressed in various laws of physics or by the relations imposed by definition of physical quantities it becomes possible to express all the units for measuring physical quantities in terms of three units known as the fundamental units of the system, v. I, p. 298. See also C.G.S. Units.

Fuse: A protection device for limiting the current which can flow in a circuit, consisting of a short length of a conductor of low melting temperature, v. IV, p. 453.

Galvanic Cell: A primary battery, v. I, p. 39.

Galvanic Electricity: Electricity in motion as distinguished from "static electricity" or electricity at rest. A term of historical interest since there is only one electricity, v. I, p. 39.

Galvanometer: An instrument for measuring current, v. I, p. 307.

Gauss: The unit of flux density. If no iron is present in a magnetic field, the flux density is the same as the magnetic field intensity.

Generator: A machine in which mechanical energy is converted into electrical energy by producing a relative motion of a coil of wire (the armature) and a magnetic field, v. I, p. 69.

Geometrical: Sometimes indicates taking account of direction as well as amount, e.g., "geometrical sum" means "vector sum".

Gilbert: That value of magnetomotive force which will establish 1 maxwell (i.e., 1 line) in a centimeter cube of air.

Greek Alphabet: The most commonly used letters are:

α = alpha
β = beta
γ = gamma
δ = delta
ϵ = epsilon
η = eta
θ = theta
κ = kappa
λ = lambda
μ = mu
ν = nu
ξ = xi
π = pi
ρ = rho
σ = sigma
τ = tau
ϕ = phi
χ = chi
ψ = psi
ω = omega
Σ = capital sigma
Δ = capital delta

Harmonic: (See Sinusoidal.)

Heat Run: A test to determine the ability of a dynamo-electric machine to deliver its specified output without overheating.

Hefner Lamp: v. III, p. 373.

Helix: A solenoid.

Henry: The practical unit of inductance, being the inductance possessed by a circuit such that changing the current flowing through it at the rate of 1 ampere per second establishes on the circuit an e.m.f. of 1 volt.

Hertzian Waves: Ether waves such as are utilized in wireless telegraphy, v. VII, p. 105.

Horn Gap Arrester: v. VI, p. 73.

Horsepower: The usual unit of power representing work being done at the rate of 550 foot-pounds per second. 1 horsepower = 746 watts.

Hot-Wire Instruments: A current-measuring instrument depending for its action upon the change in length of a wire heated by the current, v. I, p. 305.

Hunting: The action of a synchronous machine attached to an alternating-current source of power in running alternately above and below the proper speed for synchronism.

Hypothenuse: In any right-angle triangle the longest side, i.e., the side opposite the right angle.

Hysteresis: The tendency of magnetic induction in a magnetic body to lag behind the cause inducing it in amount, not time, v. II, p. 157.

Hysteresis Loop: A curve showing the relations between the various values of induction and magnetic field intensity when the latter is varied continuously from a definite value in one direction to an equal value in the other direction and back to the original value, v. II, p. 30.

Hysteresis Loss: A heat loss occurring when a magnetic body is carried through a hysteresis loop.

Hysteretic Constant: A factor giving the loss in ergs per cubic centimeter of iron per hysteretic cycle when the maximum flux density is known. (See Hysteresis Loss, v. II, p. 31.)

Ideal Transformer: A transformer assumed to exist for purposes of analysis only and differing from an actual transformer in that its iron and copper losses are assumed to be zero and there is assumed no magnetic leakage, v. IV, p. 250.

Illumination: (See Foot Candle.)

Impedance: The impedance of an alternating-current circuit is the number of volts required per ampere of current in the circuit. The unit is the ohm.

Incandescent Lamps: v. III, p. 266.

Inductance: That property of a circuit by virtue of which it offers opposition to changes in the current flowing through it, the opposition arising from an e.m.f. induced in the circuit by the current change itself, v. I, p. 37.

Induction (Magnetic): The flux density established at a point by a magnetic field in which is placed a magnetic body.

Induction Coil: A transformer; generally the term applies to a special form of transformer for producing small currents of high voltages, as those used for actuating X-ray tubes, v. I, p. 74.

Induction Generator: An induction motor whose rotor is rotated by some outside source of energy, at a speed above that at which it would normally rotate due to the alternating current in the stator, will supply energy to the mains to which its field is connected, v. IV, p. 415.

Induction Motor: An alternating-current motor whose field is supplied with alternating current, the rotation of whose armature is caused by the intersection of this field and currents induced in the short-circuited armature by the field. (See Rotor and Stator, v. IV, p. 389.)

Induction Regulator: v. IV, p. 466.

Inductive Reactance: The measure of the opposition to the passage of an alternating current through an inductance, is given in ohms as $2\pi f L$ where L is inductance in henries and f is frequency in cycles per second.

Inductivity: The ratio of the capacity of a condenser to the capacity which it would have if the dielectric were replaced by air, hence a measure of the inductive capacity of the dielectric, v. IV, p. 41.

Inductor: The part of a conductor in an armature winding which lies entirely on one side of the armature core and in which an e.m.f. may be induced.

Insulator: A non-conductor of electricity, v. I, p. 22.

Integrating Instruments: Instruments which show the summation or total effect of the thing to be measured, e.g., an integrating ampere-hour meter, v. I, p. 388 and following.

Integrating Photometer: v. III, p. 382.

Internal E.M.F.: (See External E.M.F.)

Internal Resistance: The internal resistance of a battery is the resistance offered by the battery to the passage of a current through it. If a current is taken from a battery, the difference of potential available at its terminals is less than the electromotive force of the battery by the amount of difference of potential required to overcome this resistance.

International Units: The practical units of electricity, such as the volt, ampere, ohm, joule, watt, henry, farad, are accepted by all civilized countries and are frequently called "international".

Interpoles: Magnet poles midway between the poles of the main field of a dynamo-electric machine which produce a field which induces in the armature turn passing through it a small e.m.f. in such a direction as to assist commutation and render it sparkless, v. II, p. 67.

Interrupter: A device for opening and closing an electrical circuit so as to make a rapid series of makes and breaks.

Intrinsic Brilliancy: The luminous intensity (measured in candles) per unit area of the light source.

Inverse Time Limit Relay: v. VI, p. 167.

Inverted Rotary: A rotary converter transforming direct currents into alternating currents, v. IV, p. 363.

Ion: Each of the two movable parts into which a molecule splits when dissociation takes place is called an ion, v. I, p. 49.

Iron Losses: Hysteresis and eddy-current losses in the iron of dynamo-electric machines.

Joule: The practical unit of work in electrical measurements representing the energy expended in one second by a current of one ampere flowing through one ohm, v. II, p. 12.

Joule's Law: Joule's Law states that the instantaneous expenditure of power in a resistance in an electrical circuit is as the product of the resistance and the square of the instantaneous value of the current.

Kelvin Balance: A special type of electrodynamometer, v. I, p. 320.

Kilo: A prefix applied to the name of a unit to represent a unit one thousand times as large, e.g., 1 kilowatt = 1000 watts.

Kinetic Energy: The ability to do work possessed by a system by virtue of the relative motion of its parts.

Kirchoff's Laws: Kirchoff's Laws state that in any closed electrical circuit the "algebraic sum" of all the e.m.f's and all the drops in potential due to the passage of current through resistance equals zero; also, that at any point where a circuit branches, the algebraic sum of all the currents flowing toward the point is zero, v. IV, pp. 17, 18.

Krarup Cable: v. VII, p. 28.

Lamination: The act of dividing up into strips of laminae any magnetic body otherwise subject to eddy currents. By insulating the strips from one another, eddy currents due to a field parallel to the strips are reduced, v. II, p. 31.

Lap Winding: A scheme of connection for conductors in an armature winding, v. II, p. 110.

Law of Inverse Squares: The Law of Inverse Squares states that any effect transmitted through the ether, as heat or light radiations or electrical attractions, is proportional at any point in space to the reciprocal of the square of the distance from the source to the point.

Lenz's Law: Lenz's Law states that any induced e.m.f. is in such a direction as to send through the circuit in which it is induced a current the effect of which will oppose the cause inducing it.

Leyden Jar: A convenient condenser of small capacity made by coating a glass jar both inside and outside with a conductor, e.g., tin foil.

Lead (Brush): The angle ahead or behind the "neutral axis", that the brushes bearing on a commutator are set. It is measured in "electrical degrees".

Line of Force: In a field of force one line of force is imagined to pass through a unit square at right angles to the direction of the field for each unit of force which the field would exert upon a body of unit amount (e. g., unit mass, unit magnet pole, or unit quantity of electricity) placed in the field, v. II, p. 17.

Load Factor: The ratio of the average power to the maximum power during a certain interval of time.

Loadstone: A natural magnet.

Long Shunt Compounding: A connection for a d.c. compound machine in which the shunt field winding is in parallel with the series connection composed of the armature and the series field winding.

Lumen: The unit of flux of light representing that flux which would give a uniform illumination of one foot candle, v. III, p. 325.

Lummer-Brodhum Photometer: v. III, p. 375.

M.M.F.: (See Magnetomotive Force.)

Magnet: A body which has the property of attracting pieces of iron.

Magnetic: Possessing either the properties of a magnet or properties which admit of magnetism being established.

Magnetic Circuit: The path followed by magnetic lines. Since magnetic lines are continuous the path forms a closed circuit.

Magnetic Damper: A conductor so placed as to have eddy currents induced in it when a magnetic field which it is desired to maintain constant is subjected to variation, v. II, p. 33.

Magnetic Detector: v. VII, p. 156.

Magnetic Field Intensity: The number of magnetic lines per square centimeter normal to their direction which exist in a region subject to magnetic influences but entirely free from magnetic substances.

Magnetic Induction: The act of creating a magnet from a piece of magnetic material. The measure of the magnetic effect thus produced. (See Gauss and Induction.)

Magnetic Leakage: That part of the magnetic field established by the field coils of a dynamo-electric machine which is so placed as not to be cut by the armature conductors, v. II, p. 79.

Magnetic Poles: The ends of a magnet at which the magnetism is concentrated. Poles are either north or south. A unit of magnet strength.

Magnetic Voltage Regulator: v. IV, p. 464.

Magnetism: That physical property of a magnet by virtue of which it attracts pieces of iron. The unit of magnetism is a unit pole.

Magnetization Curve: A plot showing the relation of magnetizing force and resulting magnetic induction, v. II, p. 27. See Hysteresis Loop.

Magneto (Machine): A dynamo-electric machine usually a generator whose magnetic field is obtained from a permanent magnet, v. II, p. 44.

Magnetometer: A laboratory instrument for measuring the intensity of a magnetic field.

Magnetomotive Force: The cause of magnetic induction. It is measured in gilberts or ampere-turns, v. II, p. 22.

Mains: The wires of an electrical system for the supply of power to which are directly attached machines for using this power. (See Feeder.)

Matthiessen Standard: v. V, p. 14.

Maxwell: The unit of flux.

Mean Spherical Candle-Power: A measure of the average illumination which a lamp would give upon the surface of a hollow sphere constructed about the lamp as a center, v. III, p. 286.

Mechanical Equivalent of Heat: (See Calorie.)

Mega: A prefix applied to the name of a unit to indicate a unit one million times as large, e.g., (1 mega-ohm) 1 megohm = 1,000,000 ohms.

Mercury Vapor Arc Rectifier: v. IV, p. 336.

Mesh-Connection: (See Delta.)

Micro: A prefix applied to the name of a unit to indicate a unit of one millionth its size, e.g., 1 micro-farad $= \frac{1}{1,000,000}$ farad.

Mil: One-thousandth of one inch.

Mil-Foot: A convenient unit of form for comparing resistances, being a wire 1 foot long and of circular cross section 0.001 inch in diameter.

Milli: A prefix applied to the name of a unit to indicate a unit one-thousandth as large, e.g., 1 millimeter = 0.001 meter.

Moore Tube Lamp, v. III, p. 292.

Motor: A machine in which electrical energy is converted into mechanical energy by the reaction between the current in a coil of wire (the armature) and a magnetic field, v. I, p. 70.

Motor-Generator: A combination of two dynamo-electric machines on the same shaft, one of which is used as a motor to drive the other as a generator.

Motor Rule: (See Fleming's Rule.)

Multi: A prefix meaning "many" and hence more than "two", e.g., multipolar.

Multiple: Same as "parallel".

Multiple-Unit Controller, v. V, p. 153.

Multiplex Winding: A special type of armature winding, v. II, p. 118.

Mutual Inductance: A measure of the coupling or linking together by a common magnetic circuit of two electrical circuits so that a change of current in one induces an e.m.f. in the other.

Neutral: In a system involving three or more wires, the neutral point is one symmetrical in voltage relations to the other points of the system and the neutral conductor through this point carries no current.

Neutral Axis: An imaginary line passing through the armature of a dynamo-electric machine on opposite sides of which the induced e.m.f's have opposite directions.

Nernst Lamp: v. III, p. 281.

Non-Arcing Arrester: v. IV, p. 472.

No-Voltage Release: A controller or motor starting-box so arranged as to open the circuit if the voltage is taken off the mains supplying the apparatus it protects. This prevents any damage to the apparatus due to an excessive starting current in case the voltage is again applied to the mains without notification to the motor attendant.

Oersted: The reluctance of a centimeter cube of air.

Ohm: The practical unit of resistance. It is the resistance offered to the passage of one ampere when a difference of potential or one volt is applied, v. I, p. 82.

Ohm's Law: States the relation of current, electromotive force, and resistance for any circuit, as $I = \frac{E}{R}$, v. I, p. 95.

Ordinate: If on a sheet two axes are drawn at right angles, one parallel to the bottom of the paper, this one is called the "axis of abscissas", and the other the "axis of ordinate".

Oscillation: A swinging back and forth, hence any alternations. A term usually applied to a complete wave of an alternating current or e.m.f., the maximum amplitude of which is varying.

Oscillation Transformer: v. VII, p. 141.

Oscillator: A device consisting of a "resonant" circuit and a source of energy from which a high frequency alternating current can be obtained.

Oscillograph: A sensitive galvanometer of very high period which indicates instantaneous values of current. A wave meter.

Osmium: A metal, one of the chemical elements.

Overload Release: Apparatus operating automatically to protect, by opening the circuit, dynamo-electric machinery from the excessive current due to overloading.

Panel: A unit of switchboard construction. Associated apparatus or similar apparatus is usually grouped and mounted upon the same panel. (See Switchboard.)

P.D.: (See Potential.)

Parallel: Two or more conductors are in parallel when they are so connected that each will carry a part of the current from a common source. Same as shunt or divided.

Paramagnetic: Possessing properties which admit of magnetism being established. Paramagnetic bodies, if free to turn, place themselves lengthwise in a magnetic field.

Period: The fractional part of a second occupied by one cycle, v. IV, p. 13.

Peripheral: Having to do with outside boundary of a geometrical figure, e.g., peripheral speed is the speed of a point on a circle revolving about an axis through its center, as in the case of a piece of shafting.

Permeability: The ratio of flux density in a magnetic body (e.g., iron) to the magnetic field intensity acting upon the body.

Petticoat-Type Insulator: v. V, p. 296.

Phase: The relation between two sinusoids. If both pass through their maximum values in the same direction, they are in phase; otherwise one leads and the other lags by a phase difference which is measured as an angle, v. IV, p. 29.

Phase Characteristic: The characteristic of a synchronous motor giving relation between armature current and field current, v. IV, p. 241.

Phase Transformer: A device by which a polyphase system is converted into another polyphase system of a different number of phases.

Photo-Electric: Having to do with those changes in the electrical conditions which take place in certain materials under the action of light.

Photometer: An instrument for comparing the intensities of two sources of light utilizing the "law of inverse squares" (q.v.).

Photometry: The science of measuring light.

Pitch: The frequency of a periodic disturbance which manifests itself as a musical note is a measure of the pitch of the note. Therefore pitch and frequency have become synonymous terms in telephony and wireless telegraphy.

In armature winding, the distance between one winding element and the next element which is connected directly to it as measured in number of inductors or number of commutator bars, v. II, p. 100.

Planté Cell: v. VI, p. 210.

Polar Duplex: A duplex telegraph system dependent for its operation upon the use of a "polarized relay" and batteries of different "polarity", i.e., either the positive terminal of a battery to the wire and the negative to ground or *vice versa*, v. VII, p. 45.

Plunger-Type Instruments: Galvanometers where the current is indicated by the motion of an iron core pulled up into a solenoid carrying the current against the force of gravity, v. I, p. 318.

Polarized Relay: A relay consisting of two coils carrying the current and a movable part or armature which is a permanent magnet (i.e., a polarized piece of iron) and therefore depends for its direction of motion upon the polarity given to the coils by the direction of current through them.

Polarization: A phenomenon taking place in a primary battery which tends to reduce its e.m.f.

Pole Armature: An armature whose windings are on poles projecting radially from the armature shaft, v. II, p. 42.

Pole Pitch: The distance between the centers of adjacent poles in a dynamo-electric machine as measured in number of conductors, v. II, p. 114.

Pole-Shoe: The extension affixed to the magnet core of a dynamo-electric machine next to the armature to increase the air-gap area, v. II, p. 87.

Polyphase: Two or more sources of alternating current interconnected give a system in which phase differences exist which is called polyphase.

Post Office Box: A convenient form of Wheatstone bridge.

Potential: The measure of the conditions existing at any point by virtue of which electricity will flow between this point and another point in a different condition. The potential of a point is measured as so much above or below that of the earth and represents the work that would be done in moving a unit charge from the point to the earth.

Potential Energy: The ability to do work possessed by a system the parts of which are at rest.

Potential Transformer: A transformer for use in connecting a potential measuring instrument to high voltage circuits.

Potentiometer: An arrangement of resistances and a galvanometer and source of e.m.f. whereby two other sources of e.m.f. can be compared with each other, v. I, p. 360.

Power: The rate of doing work or expending energy, v. I, p. 115.

Power Factor: The factor involving the difference of phase between the two waves by which the product of effective e.m.f. and effective current in any circuit is multiplied to give power, v. IV, pp. 36, 37.

Practical Units: Multiples or submultiples of the electrical units of the C.G.S. system, e.g., 1 volt = 100,000,000 c.g.s. units of potential.

Pressure: Force per unit area, e.g., a pressure in pounds per square inch.

Primary Battery: A battery from which an electrical current can be obtained without first passing a current through the cell in the reverse direction. (See Storage Battery.)

Primary Coil: That coil of a transformer which receives energy from the outside source.

Pulsation Test: A test of the tendency of a synchronous machine to "hunt", v. IV, p. 242.

Pupin Coils: v. VII, p. 28.

Quadrature: A phase difference of 90 degrees.

Quadruplex: A name descriptive of a telegraph system where four messages, two in each direction, can be sent simultaneously over a single circuit.

Quarter Phase: (See Two Phase.)

Radian: Unit of angular separation representing that angle subtended at the center of a circle by an arc of the same length as the radius.

Radical: A group of atoms which in chemical action behave as a single atom, e.g., the acid radical of sulphuric acid H_2SO_4 is SO_4.

Radiotelegraphy: Wireless telegraphy utilizing the phenomena of the ether by which electrical energy can be transmitted by radiation, v. VII, p. 95.

Rate: A rate is always a ratio or relation between two quantities; where the second quantity is not stated it is always time, e.g., speed = rate of change of position.

Rate of Acceleration: A term frequently used wrongly as equivalent to "acceleration" (q.v.).

Reactance: That factor which in any alternating-current circuit measures the effect of the inductance and capacity of the circuit. It may be either inductive reactance (q.v.) or capacity reactance. If both occur in series, the resulting reactance is their algebraic sum, v. IV, p. 44.

Re-Entrancy: A measure of the number of times, in tracing through the whole winding of an armature, one would return to or re-enter the conductor from which one started, v. II, pp. 106, 107.

Re-Entrant: Closing on itself.

Regulation: In any electrical apparatus, as one factor, e.g., the load, is varied some other factor, e.g., speed for a motor or voltage for a generator, is changed. The measure of such a change is called the "regulation" of the apparatus. (See Control, Speed Regulation, and Voltage Regulation.)

Regulator: An electrical device which may be connected to a dynamo-electric machine to improve its "regulation" (q.v.).

Relay: An electromagnetic device which when carrying a current opens or closes a switch in its own or another electrical circuit, v. I, p. 63, and v. VI, p. 167.

Reluctance: That property of a magnetic body by virtue of which it requires a magnetomotive force to establish a flux through it.

Remanence: (See Retentiveness.)

Remote Control: The system in which switches controlling machines and apparatus of dangerously high voltage are operated by small motors of low voltage whose operation is controlled by apparatus inserted in this low voltage circuit at a point removed from the neighborhood of the high voltage machines.

Residual Magnetism: The magnetism established in a body by the application of a temporary magnetizing force.

Repeater: A telegraph instrument for extending the range over which telegraphy is possible by receiving the weak signals at the end of a long line and actuating a sending instrument which uses energy from a source at the repeater station to send out strong signals over another line, v. VII, p. 36.

Repulsion Motor: A single-phase motor operating by the repulsion exerted upon the currents induced in the armature of the motor by an a.c. in its field windings, v. IV, p. 413.

Resistance: That property of a body by virtue of which it opposes the passage of an electric current.

Resonance: The phenomenon of particular sensitiveness to vibrations or waves of a particular frequency, v. VII, p. 111 and v. IV, p. 53.

Resonator: A simple detector consisting of a resonant circuit with a spark gap, v. VII, p. 111.

Resultant: The vector whose amount and direction is such that it represents the combined effect of several vectors.

Retardation Coil: (See Choke Coil.)

Retentiveness: The residual value of the induction in a magnetic body to which has been applied a magnetic force after the force has been removed.

Retentivity: A measure of the ability of a magnetic body to resist either magnetization or demagnetization, v. I, p. 14.

Reverse Energy Relay: v. VI, p. 167.

Reversing Starter: A starting box for a motor so connected as to admit of starting the motor in either direction of rotation.

Rheostat: A resistance which can be varied and is used in series with any desired circuit to vary the current by varying the total resistance.

Ring Armature: v. II, p. 40.

Root Mean Square: Effective value.

Rotary Condenser: A synchronous motor used as a condenser, v. IV, p. 239.

Rotary Conductor: A dynamo-electric machine whose armature windings are connected both to a commutator and to slip rings so that the machine can be used either as a direct-current or as an alternating-current machine or both. If used as a d.c. motor, an a.c. may be obtained from it. If used as an a.c. motor a d.c. may be obtained from it. It is then called "inverted", v. IV, p. 341.

Rotor: The short-circuited armature of an induction motor.

Rousseau Diagram: A diagram for calculating the mean spherical candle-power from a limited number of photometer readings, v. III, p. 387.

Saturation (Magnetic): That state attained by a magnetic substance under the action of a magnetizing force when an increase in the force produces no increase in magnetization.

Saturation Characteristic: The characteristic giving the relation between the armature e.m.f. of a synchronous machine and its field current, v. IV, p. 205.

Scalar: A quantity which is not associated with a direction. (See Vector.)

Scott Transformer Connection: A connection of two transformers whereby a three-phase system may be changed into a two-phase system or *vice versa*, v. IV, p. 273.

Secondary Coil: That coil of a transformer which delivers energy. (See Primary Coil.)

Segments: Portions of a circle bounded by an arc or portion of the circumference, as the segments of a rotary commutator.

Selenium Cell: A photo-electric cell composed of pieces of selenium the resistance of which decreases when it is exposed to light waves, v. VII, p. 184.

Self-Inductance: Same as inductance.

Series: Two or more conductors are connected in series when they are so joined that a current can flow from one to the next without either being increased or decreased in amount. (See Parallel.)

Series Generator (or Motor): One where the magnetic field is established by the same current as passes through the armature, the field coils and the armature being connected in series, v. II, p. 45.

Shell-Type Transformer: v. IV, p. 284.

Shunt: A conductor is in shunt with another conductor when the two are connected in parallel. Each then forms a shunt to the other. (See Parallel.)

Short Circuit: A connection which permits current to flow from one part of a circuit to another part by either a path it is not desired it should take or a path of negligible resistance.

Short-Shunt Compounding: A connection for a d.c. compound machine in which the shunt field winding is in parallel with the armature only; the series field winding is in series with the divided circuit composed of the armature and shunt field.

Shunt Generator (or Motor): One where the armature and the field coils are in shunt or parallel, v. II, p. 46.

Simplex: A name descriptive of a telegraph system where but one message can be sent at a time over a single circuit. (See Duplex.)

Simplex Winding: A special type of armature winding, v. II, p. 118.

Sine: The sine of an acute angle (e.g., θ), written "sin θ", is the ratio in any right-angle triangle constructed on this angle of the length of the side opposite the angle θ to the length of the hypothenuse of the triangle.

Sine Curve: (See Sinusoid.)

Singing Arc: v. VII, p. 147.

Single Phase: Any single source of alternating current constitutes a single-phase system. Polyphase systems are built up from connections of synchronous single-phase systems.

Sinusoid: A variable the values of which when plotted against time gives a wave similar to that obtained by plotting the values of the sine of an angle against the continuously increasing value of the angle. (Note: For angles greater than 90° the value of the sine can be expressed in terms of the sine of an acute angle as defined in this glossary).

Siphon Recorder: A recording D'Arsonval galvonometer in which ink flows through a pen attached to the movable coil as the result of a siphon action, v. VII, p. 85.

Skin Effect: An alternating current tends to flow in the outer portion of a conductor more readily than in the inner portion so that the effective conducting area is decreased and the effective resistance increased.

Slip: The per cent of the synchronous speed of an induction motor by which its actual speed differs from synchronism, v. IV, p. 482.

Slip Ring: (See Collector Ring.)

Solenoid: A coil of wire wound like a spiral spring or an ordinary spool.

Space Degrees: In one revolution the shaft of an alternating-current machine produces a relative displacement of the armature and the field poles of 360 space or geometrical degrees. The rotation which must occur in order that the armature coil shall be displaced from a position opposite one north field pole to a position opposite the next adjacent north field pole is 360 electrical degrees. (See Electrical Degrees.)

Space Factor: The ratio of the cross-sectional area of copper in a winding to the total cross-sectional area occupied by the winding, the insulation, and the air spaces, v. II, p. 92.

Spark Gage: High voltages are sometimes measured by the distance in air across which they can cause an electrical discharge, v. IV, p. 105.

Specific Heat: A measure of the amount of heat (energy) required to raise a unit mass of the substance 1 degree, usually referred to the amount of heat required to raise the same mass of water one degree taken as unity.

Specific Resistance: A measure of the characteristic ability of a particular substance to transmit electrical currents, hence depending only upon the substance and not on the form of the conductor, v. I, p. 46.

Speed Regulation: The per cent of the full-load speed that the speed of a motor changes, if the load is changed from full load to no load.

Split Phase: A single-phase alternating-current supply can provide current of different phases to several branches in parallel, if the power factors of the branches are different, v. IV, p. 412.

Squirrel Cage: The form assumed by the conductors in the rotor of an induction motor.

Static Machine: A machine for producing electrification. (See v. I, p. 37.)

Star Connection: (See Y Connection.)

Stator: The field winding of an induction motor.

Stillwell Regulator: v. IV, p. 462.

Storage Battery: A cell in which electricity can be stored by the passage of an electric current which produces certain chemical changes that are reversible and, if allowed to reverse, will cause a current to flow.

Stray Currents: Those which follow leakage paths in passing between the terminals of the generator supplying power to a system, e.g., currents in electric traction which instead of returning through the return rail pass through the ground and through conductors belonging to other systems.

Stray Power: Those power losses of a dynamo-electric machine which are not directly calculable and are due to various heating effects, such as friction, hysteresis losses, and eddy-current losses, v. II, p. 72.

Substation: A station in a system for distributing electrical energy which is supplied with electrical power from the central station and serves as a power station for supplying its immediate neighborhood. A substation usually serves to transform the power it receives or to regulate its voltage, or both.

Sulphating: A chemical action in storage batteries of the lead type of a very destructive nature, v. VI, p. 240.

Susceptance: A component part of the admittance of a circuit, being $b = \frac{x}{r^2 + x^2}$ where r is the resistance and x is the reactance of the circuit, v. IV, p. 63.

Switchboard: The supports upon which are held the switches, rheostats, measuring instruments, etc., essential to the control of part or all of an electrical system. The apparatus is usually mounted upon several vertical slabs of insulating material adjoining each other and known as the "panels" of the switchboard.

Synchronizer: A synchronoscope.

Synchronizing: The act of so adjusting the speed of an alternating-current machine that its frequency is the same as that of some other source of alternating currents.

Synchronous: Having the same frequency.

Synchronous Compensator: (See Rotary Condenser.)

Synchronous Impedance Characteristic: The characteristic giving the relation between the armature voltage and the armature current. The ratio of these two gives a fictitious impedance, hence the name, v. IV, p. 209.

Synchronous Motor: An alternator is capable of running as a motor provided it runs in synchronism with the alternator supplying it, v. IV, p. 228.

Synchroscope: A device for indicating when two sources of alternating currents have the same frequency, v. IV, p. 451.

Syntonic: Of similar tone, pitch, or frequency, hence resonant.

Tachometer: An instrument for measuring speed, more particularly the speed in number of revolutions per second or per minute of a revolving shaft.

Tangent Galvanometer: A laboratory type of galvanometer which admits of an absolute measurement of current. (See Absolute Measurement, v. I, p. 308.)

Tantalum: A metal, one of the chemical elements.

Tapering Feeders: A method using feeders (wires) of various sizes in distributing energy to a number of loads in parallel so that the voltage regulator at every load will be approximately the same, v. III, p. 290.

Teeth: An armature has its windings imbedded in slots in the armature core. The iron separating these slots form teeth.

Telephone: An arrangement by which sounds are received, converted into electrical waves, transmitted over a distance, and finally converted back into sounds, v. I, pp. 76-79.

Temperature Coefficient: The amount per degree change of temperature that the quantity under consideration changes, e.g., temperature coefficient of resistance, v. I, p. 90.

Tensile Strength: A measure of the force required per unit cross-sectional area to pull in two a given material.

Three Phase: A system formed by interconnecting three sources of alternating currents which have voltages differing in phase by 120°, v. IV, p. 133.

Three-Wire System: A direct-current system of distribution in which a "neutral" wire is used which is as much below one wire in voltage as it is above the other.

Tirrill Regulator: v. IV, p. 126.

Toroid: A winding of wire around a ring-shaped core the cross section of which is a circle, v. II, p. 20.

Torque: Moment (i.e., importance) of a force in producing rotation; it is measured by the product of the force and the length of the lever arm or perpendicular distance from the axis to the line of direction of the force.

Traction: The act of pulling or drawing; hence, electrical traction is the drawing of cars by utilizing energy received in the form of electrical energy.

Tractive Effort: The net force tending to accelerate a train, being torque in pounds developed at the rim of the driving wheels divided by the total train weight including a weight equivalent to the train resistance losses.

Transformer: An arrangement of two coils of wire on the same iron core whereby an alternating (or variable) current in one coil, the primary, induces a current in the other coil, the secondary, v. I, p. 71; v. IV, 247.

Transposition: An interchange introduced at intervals along a transmission line in the position of the conductors to reduce the mutual inductance between various circuits, v. V, p. 45.

Trolley: A small wheel; hence the small wheel used in electric traction for making contact with the wire supplying current to the moving car.

Tune: To change the pitch of; hence to change the electrical frequency of a circuit until it is resonant at a desired frequency. (See Pitch.)

Tungsten: A metal, one of the chemical elements, which is much used in making incandescent lamp filaments.

Two Phase: A system, which is formed by interconnecting two sources of alternating currents so that the voltages of the two sources differ by 90°, is called two phase, v. IV, p. 130.

Tub Transformer: A constant-current transformer formed of two coils, one movable which tends to place itself so that the "coupling" is such as to maintain a constant output current, v. IV, p. 313.

Underwriters' Wire: v. I, p. 187.

Uni: A prefix meaning "one"; e.g., unipolar.

Universal Shunt: An "Ayrton Shunt", so-called because the fractions in which it divides the given current are independent of the resistance of the current measuring instrument.

Valency: The measure of the combining power of the atoms of a substance expressed in terms of the number of atoms which are held in combination by a single hydrogen atom or by an atom which would combine with one atom of hydrogen.

V-Connections: A scheme of connection for two transformers adaptable to a three-phase system, v. IV, p. 270.

Vector: A directed quantity; e.g., a magnetic field strength is a vector since it has both amount and direction. Such a quantity is best represented by a line having the proper direction and a length proportional to its amount.

Vector Parallelogram: The sum of two vectors is the diagonal of the parallelogram constructed on the two vectors (drawn from a common point) as sides.

Vector Polygon: The sum of two or more vectors is represented by drawing each vector in its proper direction, as the sides of a polygon, and then drawing from the origin to the extremity of the last vector.

Volt: The practical unit of electromotive force or potential difference. It is equal to $\frac{1000}{1434}$ parts of the e.m.f. of a certain type of primary battery known as the Clark standard cell, v. I, p. 82.

Voltmeter Compensator: v. IV, p. 468.

Voltage Regulation: The per cent of the full-load voltage that the terminal voltage of a generator changes, if the load is changed from full load to no load.

Voltaic: A term equivalent to "galvanic", v. I, p. 39.

Volt-Ampere: For steady currents this is a rarely used unit equal to the watt. For alternating currents it is a unit used for expressing the power rating of machines.

Voltameter: A device for measuring the quantity of electricity which passes through it by the electrolytic effect of the current.

Voltmeter: An instrument for measuring differences of electrical potential in volts, v. I, p. 44.

Watt: The practical unit of power in electrical measurements, being an expenditure of energy at the rate of one joule per second, v. II, p. 12.

Wattless Current: That component of the current which is due to the reactance of a circuit and, being 90° out of phase with the voltage, does not represent an energy expenditure.

Wattmeter: An electrodynamometer with one coil connected to show the current and the other to show the difference of potential calibrated to indicate power in watts, v. I, p. 323.

Wave: The plot of the values of any alternating quantity, e.g., alternating current, against time gives a wave-like curve of which the plot for one complete cycle is called a "wave", v. IV, p. 23.

Wave Winding: A scheme of connection of inductors in an armature winding, v. II, p. 110.

Weatherproof Wire: v. I, p. 273.

Wehnelt Interrupter: v. VII, p. 138.

Weston Cell: A primary battery used as a standard of e.m.f., v. I, p. 300.

Wheatstone Bridge: An arrangement of two known variable resistances, one known fixed resistance, and a battery and a galvanometer whereby a fourth resistance entirely unknown can be quickly measured, v. I, p. 341.

Windage: The power loss due to air friction which occurs in a rotating machine, v. II, p. 143.

Winding Pitch: (See Pitch.)

Work: When motion is produced by the action of a force, work is done.

Y Connections: A scheme of connections in three-phase systems.

Yoke: That portion of the iron of the magnetic circuit of a dynamo-electric machine which connects the magnet cores of the field coils.

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REVIEW QUESTIONS

REVIEW QUESTIONS

ON THE SUBJECT OF

MODERN LAND AND SUBMARINE TELEGRAPHY

---

1. State the merits of the Morse telegraph

2. Compare the merits of wireless vs. submarine telegraphs.

3. What is the purpose and structure of an artificial cable?

4. Compare the merits of the open-circuit telegraph with those of the closed-circuit telegraph.

5. How many gravity cells in series (each cell having an e. m. f. of 1.08 volts and an internal resistance of 2 ohms) would be needed to operate an ordinary 5-ohm sounder in the local circuit of a line relay?

6. To compensate for the leakage, should the applied e. m. f. be increased or decreased?

7. Why is the polar duplex much more reliable than the Stearns duplex?

8. Explain how, in a quadruplex system, two messages may be sent simultaneously in the same direction without interference.

9. What are the advantages of the Morkrum telegraph?

10. What are the general features of the Wheatstone automatic telegraph.

11. By what means did Delany overcome the effect of the line capacity so as to distinguish dot from dash signals in his high speed automatic system?

12. What is the telegraph fault known as the bug and how may it be eliminated?

13. Explain why it was necessary to employ both series and shunt circuits in the dynamo duplex known as the Field key system.

14. Why are double keys used in sending signals through submarine cables?

15. Make a drawing representing a serpentine cable record tape on which the word "study" is recorded. (Use Continental code).

16. How is the friction of contact in the Brown drum cable relay reduced?

REVIEW QUESTIONS

ON THE SUBJECT OF

WIRELESS TELEGRAPHY

1. What is meant by *conduction systems* and *induction systems* of wireless telegraphy?

2. Draw a diagram showing how a river may be used in place of telegraph lines.

3. What is meant by *radiotelegraphy?*

4. What is meant by the ether? By radiant energy?

5. What is meant by an oscillatory discharge, and what kind of waves are produced by oscillatory discharges?

6. What is meant by resonance? Sympathetic vibration?

7. What is meant by two circuits being "in tune"? What two characteristics of a circuit determine its frequency?

8. What is the characteristic of a closed oscillatory circuit? An open one? Draw two types.

9. Which are the longer ether waves—light or Hertzian waves? What is their velocity?

10. What is meant by the Righi oscillator? By the Branley coherer?

11. What effect do electric waves have upon powders and metal filings?

12. Explain what is meant by *inductive receiving antennae.* Draw a diagram.

13. What is an oscillation transformer? Should the open oscillatory circuit of the antennae and the closed oscillatory circuit be "in tune"? Why?

14. What is meant by selective signaling?

15. Name two different pieces of apparatus which may be used to charge the aërial.

REVIEW QUESTIONS

ON THE SUBJECT OF

WIRELESS TELEPHONY

---

1. What is a Bell radiophone?

2. What is the effect of light on selenium? What is the photophone?

3. Describe the method of causing a direct-current arc to emit musical and other sounds.

4. What is the principal difficulty encountered in applying Hertzian waves to the problem of wireless telephony?

5. Why could not a common telephone transmitter be efficiently used as an interrupter for an induction coil in the production of high-frequency oscillations?

6. What is meant by intermittent wave trains?

7. Describe the method of superimposing a telephone current upon a constantly operating source of oscillations of high intermittency.

8. Name two different methods of creating sustained oscillations.

9. Draw a diagram of the Fessenden method of transmitting radiotelephonically by use of the high-frequency alternator.

10. Name the two most common methods of producing sustained oscillations.

11. Draw three different ways of connecting a telephone carbon transmitter to the oscillatory circuits in order to vary the energy of the radiation therefrom in accordance with the voice current.

12. What detectors may be used for radiotelephony? May a coherer be used?

13. Describe the action of the Fessenden "heterodyne" receiver.

14. Tell why two-way transmission in radiotelephony is not as simple of accomplishment as in ordinary wire telephony.

REVIEW QUESTIONS

ON THE SUBJECT OF

ELECTRIC ELEVATORS

---

1. Give a description of an early type of elevator installation.

2. What are the requirements for motors?

3. Describe an interpole motor.

4. What difficulties are encountered in using alternating-current motors for elevator work?

5. What are the functions of a controller?

6. In what particular points does an elevator controller differ from an ordinary motor starter?

7. Give diagram and description of a semi-automatic control for compound-wound dynamos.

8. Describe the mechanically-operated type of alternating-current controller.

9. Give wiring diagram for a three-phase elevator equipment with mechanical control.

10. Give sketch of a single-speed full-magnet controller with explanations of its working.

11. Give a short description of an elevator using push-button control.

12. Discuss the points which have to be considered in regard to the location of an elevator engine.

13. What are the advantages claimed for the tandem-geared engine?

14. In what case are double-threaded worms employed?

15. Give description and sketch of a worm-shaft thrust-block.

16. What is the usual speed of elevators which have a travel of less than one-hundred feet?

17. What is the counterpoise weight and what is its purpose?

18. What is a traction elevator?

REVIEW QUESTIONS

ON THE SUBJECT OF

WELDING

1. What are the four general classes of welding processes?

2. Discuss the general features of smith welding.

3. What is a scarf weld?

4. Give some applications of smith welding.

5. What is soldering?

6. What tools are necessary for soldering?

7. Give the general features of the electric welding processes.

8. Describe the Benardos system of electric-arc welding.

9. Discuss the advantages of low voltage generators in welding.

10. Make wiring diagram of a Westinghouse arc welder.

11. Describe the Siemund-Wenzel welding system.

12. Make wiring diagram for the C & C welding system.

13. Discuss the cost of arc welding.

14. Discuss the processes of welding by resistance.

15. What is jump welding?

16. How is the power required for butt and spot welding determined?

17. What are the requirements for the strength of a weld?

18. What is blau gas?

19. Give the general features of the oxy-acetylene weld.

20. Describe the equipment used for oxy-hydrogen welding.

GENERAL INDEX

GENERAL INDEX

In this Index the *Volume number* appears in Roman numerals—thus, I, II, III, IV, etc., and the *Page number* in Arabic numerals—thus, 1, 2, 3, 4, etc. For example, Volume IV, Page 327, is written IV, 327.

The page numbers of this volume will be found at the bottom of the pages; the numbers at the top refer only to the section.

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